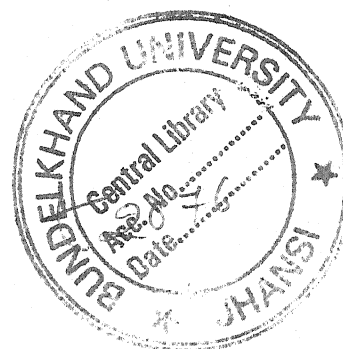
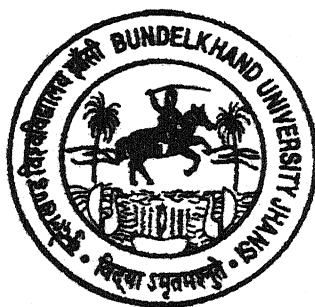


**PHENOTYPIC STABILITY OF SOME  
WHEAT (*Triticum aestivum* L.) GENOTYPES  
UNDER BUNDELKHAND CONDITIONS**

**THESIS**

SUBMITTED TO  
**THE BUNDELKHAND UNIVERSITY  
JHANSI, U. P. (INDIA)**



FOR THE DEGREE OF  
**DOCTOR OF PHILOSOPHY**  
IN  
**GENETICS AND PLANT BREEDING**

By  
**SURENDRA SINGH**  
UNDER THE GUIDANCE OF

**Dr. S. P. Singh**

Reader and Head

Department of Genetics and Plant Breeding  
Brahmanand Mahavidyalaya, Rath (Hamirpur) U. P.

**2005**

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# BRAHMANAND MAHAVIDYALAYA

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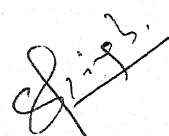


## CERTIFICATE

This is to certify that the thesis entitled “ Phenotypic stability of some wheat (*Triticum aestivum* L.) genotypes under Bundelkhand conditions” submitted to the Bundelkhand University, Jhansi for the award of degree of Doctor of Philosophy in Genetics and Plant Breeding is a record of bonafide research work carried out by Mr. Surendra Singh under my supervision.

The manuscript pertains to the original work of the candidate. He has worked under my supervision for more than 24 months commencing from the date of his registration as required under the Ph. D. degree ordinance of the University and has put in the required attendance for more than 200 days in the department during the period.

Place : Rath

  
(Dr. S. P. Singh)

Date : 31.08.2005

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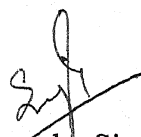
I would be failing in my duty if I do not express my sincere thanks to my colleagues Dr. G.S. Babeley, Reader and Head, Department of Botany; Dr. Kailash, Reader and Head, Department of Physics; Shri Balvant Singh, Lecturer, Department of Genetics and Plant Breeding; and Dr. Umakant Singh, Lecturer, Department of

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Dated 31-8-2005

  
(Surendra Singh)

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Chapter 1

# INTRODUCTION

## INTRODUCTION

Wheat (*Triticum aestivum* Linn. Em. Thell.) is the mainstay of foodgrains and occupies foremost position in production and area both at national and global levels. Globally, it is grown in 208.77 million ha area with 556.35 million metric tonnes production during 2002-2003. It accounts for 35 per cent of the global food supply and meets 20 per cent of the total global calorie need. Globally, the area and production under wheat have been continuously increasing since 1965-66, thanks to the development and spectacular adoption of semi-dwarf, photo-insensitive and nitrogen responsive varieties of wheat worldwide. Wheat cultivation is mostly concentrated in the northern hemisphere and cultivated under varied climatic conditions. The most extensive production of wheat comes from areas where winters are cool and summers are hot.

Wheat is an ancient cereal crop in India with wide geographical adaptation. During 2003-04, the country produced 72.06 million metric tonnes of grains from an area of 26.62 million ha with an average yield of 2.71 metric tonnes per ha. India has emerged as the second largest wheat producing country after China in the world and contributed 12.8 per cent to the global kitty. Wheat occupies about 22.3 per cent of the total area under foodgrains in the country and ranks second in area and production after rice. It plays a major role in the agrarian economy of the country. Recent trends in food habits of the people in traditional rice consuming area also point towards the positive change in favour of wheat. There is a positive correlation between wheat consumption and household income. As income goes up, consumption of wheat also

goes up. The wheat production has been revolutionized after the advent of the Green Revolution in India. It was possible only due to the introduction of semi-dwarf wheat varieties which were dwarf in nature, photo-insensitive, and responsive to better agricultural practices. The per capita availability of wheat in India has also gone up considerably during the past four decades from 90.5 g in 1967 to 178.9 g per day in 2003.

Uttar Pradesh is one of the most important wheat producing states in the country with area of 9.09 million ha, production of 23.61 million metric tonnes and average yield of 2.60 tonnes per ha. The importance of Uttar Pradesh can be judged from the fact that it accounts for 36% of the wheat area as well as production in the country. In spite of the availability of fertile land, irrigation and fertilizers, the average productivity of wheat in Uttar Pradesh (2.60 tonnes per ha) is lower than that recorded in Punjab (4.2 tonnes per ha) and Haryana (4.05 tonnes per ha). Among various factors contributing to low yield in the state, the major ones are late sowing, inefficient use of fertilizers, low varietal replacement, poor seedbed preparation after rice, low and uncertain water supply, deficiency of nutrients, poor crop management, problem soils, and menace of termite under dryland conditions. In spite of these, Uttar Pradesh grows wheat in nearly 75% of the total *rabi* cropped area of which 85% is under irrigation. The remaining area is rainfed and mostly concentrated in the Bundelkhand region.

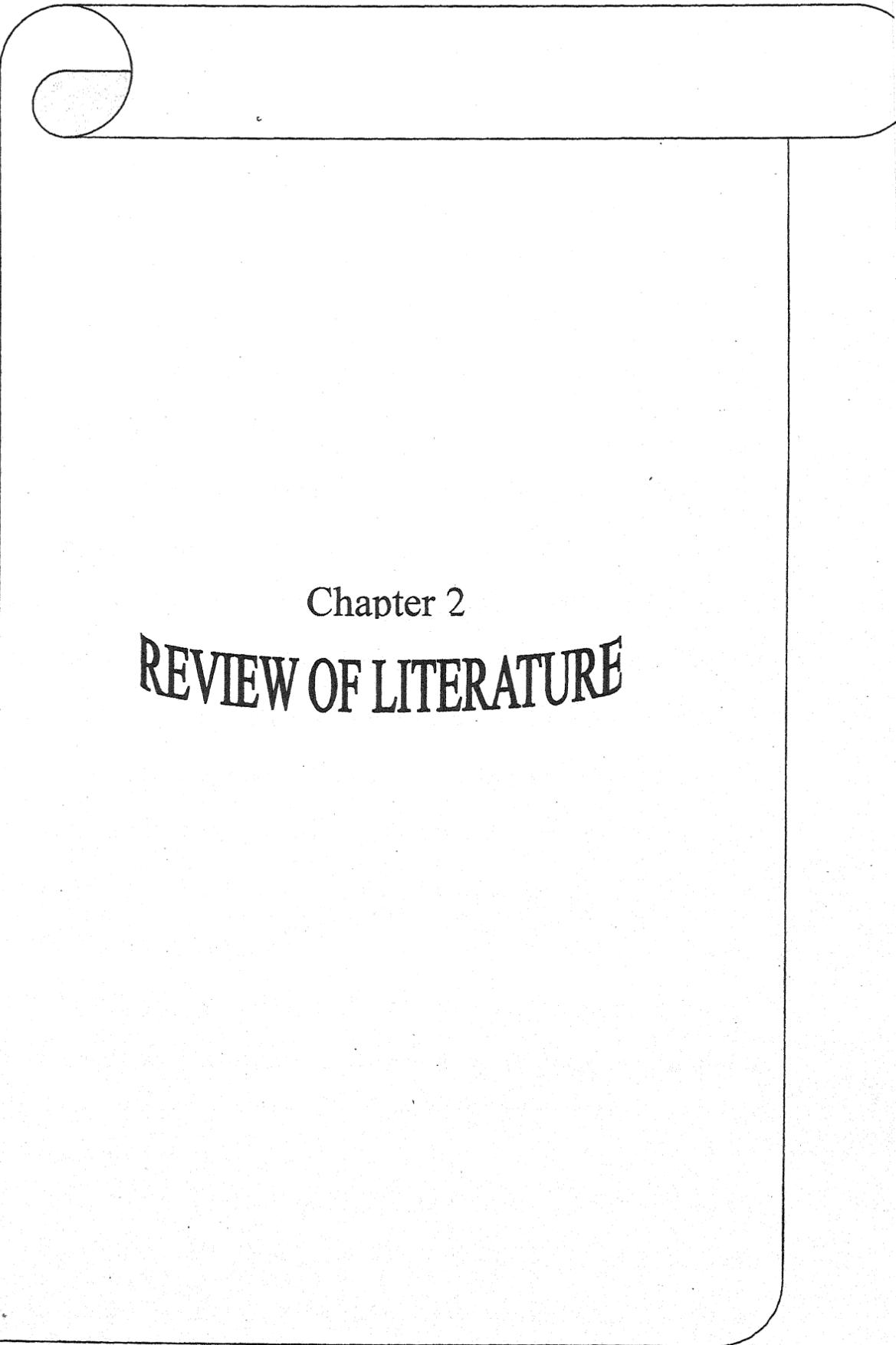
Although wheat has recorded compound growth rates of 1.31% in area, 4.11% in production and 2.76% in yield between 1967-68 and 2003-04, the average growth in productivity has been slowed down to 1.43% during the past ten years (1994-95 to

2003-04). This is a cause of concern as the average productivity has gone below the population growth rate. In order to meet the increasing demand of growing population, this trend of wheat productivity needs not only to be accelerated but also be achieved from the less endowed areas like Bundelkhand. To increase the production of wheat in Bundelkhand region, the classical approach of better agro-techniques is still meaningful. Varieties suitable for late sown conditions are required for Bundelkhand region. Sowing time, spacing, seed rates, fertilizer application and water supply are directly helpful for improvement in yield and quality in such situations.

Yield stability has always drawn attention of wheat breeders and as a result, received paramount importance among breeding objectives. Therefore, varieties with stable performance under varied agro-climatic conditions need to be developed for the Bundelkhand region as fluctuating low-yielding environments are rule than exception in Bundelkhand. In order to identify stable and widely adapted varieties, several methods of stability have been employed. Prominent among them are the ones proposed by Plaisted and Peterson (1959), Plaisted (1960), Wricke (1962), Finlay and Wilkinson (1963), Eberhart and Russell (1966), Perkins and Jinks (1968a), Hanson (1970), Freeman and Perkins (1971), Tai (1971), Shukla (1972), Pinthus (1973) and Nassar and Huhn (1987). Various concepts and measures of stability originating due to different outlooks of researchers to their specific problems have added to the difficulty of choosing a stability parameter for a given situation.

Therefore, the present study “**Phenotypic stability of some wheat (*Triticum aestivum* L.) genotypes under Bundelkhand conditions**” was undertaken with the following objectives:

- To assess the amount and nature of genotype x environment (GE) interaction
- To determine the stability parameters for adaptation of newly developed genotypes
- To identify high yielding and stable genotypes for Bundelkhand region
- To assess different stability parameters for their effectiveness in measuring the GE interaction

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Chapter 2

**REVIEW OF LITERATURE**

## REVIEW OF LITERATURE

Interaction of genotypes with environments (GE interaction) has been identified as the major cause behind unstable performance of a genotype in response to differential environmental factors/stresses. GE interaction affects breeding programme at every stages as it has a strong confounding effect on different genetic parameters like heritability, genetic correlations and finally genetic gains. Plant breeders are also interested to discern how much of the selection progress achieved in one environment can be translated in another environment. Genotype and environment are the two main ingredients that make up a phenotype. A genotype may specify a range of phenotypic expressions as gene expression is known to be environmentally induced and regulated depending upon the optimal, suboptimal or super optimal supplies of different environmental factors. The genetic constitution of an individual does not change from one environment to another, unless the environment is such to induce a mutation. Therefore, any phenotypic variation for a specific genotype is attributable to the environment and GE interaction. Quantitative traits which are controlled by polygenes and exhibit continuous variation are highly influenced by environments. As a result, the reliability of phenotype as an indicator of genotype is reduced drastically in traits like yield which is controlled by polygene and have low heritability.

Stability of a genotype may be defined as its property to perform uniformly under a wide range of environments. Failure of a genotype to give the same phenotypic performance when tested under different environments is the reflection of

the GE interaction. In case the variance due to GE interaction is found significant, one of the various approaches known for measuring the stability of genotypes can be used and the varieties may be ranked accordingly.

Becker (1981) distinguished two basic concepts of stability known as biological and agronomic concepts. The former is a static concept, where a stable genotype is one with constant performance irrespective of the quality of the environments, i.e., minimum variance across environments. This idea of stability is in agreement with the concept of homeostasis widely used in genetics. The latter concept, also known as dynamic concept, permits a predictable response to environments, i.e., a stable genotype has minimum GE interaction. There are various stability parameters that quantify these concepts. Among them, the regression coefficient ( $b_i$ ) adopted by Finlay and Wilkinson (1963) and deviation from regression ( $S^2_{d_i}$ ) proposed by Eberhart and Russell (1966) have extensively been used in plant breeding trials despite theoretical objections to their validity (Becker and Leon, 1988). Other parameters viz., coefficient of variation ( $CV_i$ ), environmental variance ( $S^2_{e_i}$ ) and those proposed by Plaisted and Peterson (1959), Plaisted (1960), Wricke (1962), Perkins and Jinks (1968a), Hanson (1970), Freeman and Perkins (1971), Tai (1971), Shukla (1972), Pinthus (1973) and Nassar and Huhn (1987) have seldom been used as stability measures in spite of being theoretically sound and their potential ability to detect GE interaction.

Plaisted and Paterson (1959) presented a method to estimate the variance components of variety x location interactions. A combined analysis of variance over all locations was computed for all possible combinations of pairs of varieties. The

variety with smallest mean value of interaction variance (variety x location) was considered the most stable variety. This technique was most cumbersome with the increase in number of varieties as the number of calculations for individual variety increased.

Finlay and Wilkinson (1963) utilized the technique proposed by Yates and Cochran (1938) and quantified the adaptability of the genotype by calculating the linear regression of yield on the mean yield of all the genotypes for each location and season. A cultivar with regression coefficient  $b_i = 1$  has average stability,  $b_i > 1$  has above average stability,  $b_i < 1$  has below average stability and  $b_i = 0$  absolute phenotypic stability (i.e., constant yield in all environments).

Eberhart and Russell (1966) improved the regression technique suggested by Finlay and Wilkinson (1963) by adding another stability parameter i.e., deviation from regression ( $S^2d_i$ ) to describe the performance of genotype over an array of environments. They pointed out that regression of each cultivar on environmental index was a function of the required deviation from the regression and would provide useful estimates of stability.

Perkins and Jinks (1968a) bridged the gap between two approaches namely, statistical approach (Yates and Cochran, 1938; Finlay and Wilkinson, 1963; Eberhart and Russell, 1966) and the approach based on contribution of genetic, environmental and their interactions to generation mean and variances (Mather and Jones, 1958; Jinks and Stevens, 1959; Bucio-Alains, 1966) and developed a model to measure the stability of genotypes. The expectations of statistical analysis were expressed in terms

of gene, environmental action and genotype x environment interactions. They extended the analysis to cover many inbred lines and crosses among them. They also concluded that while a significant proportion of the genotype x environment interaction component was linear function of the environmental components, there was still significant remainder which was not linear. Perkins and Jinks (1968b) explained the non-linear component of interaction by grouping varieties into homogeneous group on the basis of deviation from linear regression and reported a significant and marked reduction in the remainder component of the interaction as a result of grouping of varieties.

Freeman and Perkins (1971) questioned the stability models proposed by Eberhart and Russell (1966) and Perkins and Jinks (1968a) regarding the relationship between the two stability parameters. According to these models, the performance of a genotype in a given environment is regressed over the environmental index. Obviously, the estimation of these two parameters is not independent. Freeman and Perkins (1971) reported an independent estimate of environmental index by dividing replications into two groups (one group for measuring average performance of genotype in various environments and other for estimating the environmental index) and by using one or more genotypes as checks to assess the environmental index on the basis of their performance. They further questioned the earlier two models regarding the partitioning of degree of freedom. Though, sum of square due to environment (linear) of Eberhart and Russell's model were same as sum of square due to environment (joint regression) of Perkins and Jinks's model, yet the degree of

freedom is one in the former case and 'e-1' (where 'e' is the number of environments) in latter case.

The additive main effect and multiplicative interaction (AMMI) method integrate analysis of variance and principal components analysis into a unified approach (Gauch and Zobel, 1988). AMMI analysis first fits the additive effects of genotypes and environments by the usual ANOVA and then describes the GE interaction by principle component analysis (PCA). The AMMI method is used for three main purposes. The first is for model diagnosis. AMMI is more appropriate in the initial statistical analysis of yield trials, because it provides an analytical tool for diagnosing other models as sub-cases, when these are better for a particular data set. The second use of AMMI is to clarify GE interaction. AMMI summarizes patterns and relationships of genotypes and environments. The third use is to improve the accuracy of yield estimates. Gains have been made in the accuracy of yield estimates that are equivalent to increasing the number of replicates by a factor of two to five. It combines regular ANOVA for additive main effects with PCA for multiplicative structure within the interaction.

Some of the above stability parameters have been compared statistically elucidating useful theoretical interrelationships among them (Becker, 1981; Lin *et al.*, 1986 and Kang *et al.*, 1987). Besides theoretical relationships, empirical correlation is also useful to quantify interdependence of different stability parameters particularly between those whose mathematical models are inexplicit in showing their mutual relations. Based on correlations between stability parameters, Kumar *et al.* (1997) concluded that (i) the  $S^2_i$  and  $b_i$  may be used interchangeably as a stability measure

according to the static concept. However,  $S^2_i$  may be preferred when data do not follow the linear model as is the case with most of the yield trials, (ii) all parameters of the dynamic concept are equivalent for ranking of genotypes and with careful interpretation, any one of the parameters may be sufficient to provide stability measure of a genotype in relation with the genotypes included in the trial, and (iii) the  $b_i$  and  $S^2d_i$  characterize GE interaction comprehensively only if data fits the linear model. Otherwise,  $S^2_i$  along with  $\sigma^2_i$  or  $W^2_i$  may be preferred which are more directly related with the stability concepts.

### Work done on Wheat

Tunio and Frohberg (1973) presented data on six characters for 22 genotypes of wheat. Significant differences between genotypes for all characters were observed. ND264 had an average mean for heading date and a low adaptability to environments favourable for late heading. Polk had a higher than average mean for heading date and the highest adaptability to environments favourable for late heading. Tzpp was the earliest-heading variety. Forx had high average test weight. ND264 adapted well to environments favourable for grain protein but had lower average protein content than ND442. Selkirk and Mexipak performed well in environments unfavourable for grain protein content. Magnif had the highest average 200-kernel weight and the second highest adaptability to environments favourable for this character.

Bains and Gupta (1974) studied stability of yield and yield components in segregating populations of six crosses in *Triticum aestivum*. Stability of spikes per plant was closely related to yield stability in all six crosses. The importance of grain size and grains per spike in imparting yield stability was variable and suggested that either singly or jointly their stability, together with that of spikes per plant, could ensure homeostasis resulting in yield stability. No relationship was observed among the stability parameters of the yield components, suggesting that independent genetic mechanisms govern their response to environmental variation.

Eberhart *et al.* (1974) tested eight varieties under 24 environments over two successive years. The models of Eberhart and Russell, Perkins and Jinks and Freeman and Perkins were applied to study genotype x environment interactions. The correlations between different environments were determined and also the partitioning of sum of squares due to genotype x environment interaction attributable to each variety. The major findings of the study were as follows: (i) The models of Eberhart and Russell, and Perkins and Jinks produced similar results with respect to both responsiveness (b) and stability  $S^2d_i$ . Freeman and Perkins' model produced similar results to these two models for the pattern of b values; (ii) The pattern of correlations between environments (r) for various genotypes showed high similarity with the pattern of b values obtained with the various models and varieties with high b values had high environmental correlations; and (iii) Ecovalence calculations and Freeman and Perkins' model gave similar results in determining the stability of a genotype but correlations between ecovalence and Eberhart and Russell's model were low. However, most stable varieties could be detected using any of these models. The

use of correlation between environments and ecovalence is suggested for predicting responsiveness and stability of genotypes, respectively.

Bains (1976) analyzed GE interactions for grain yield in parental and successive generations of six crosses in *Triticum aestivum*. Six parental lines were chosen for these crosses on the basis of their known linear regression on additive environmental means, deviations from linearity and mean performance. Six crosses, two low x low, two low x high and two high x high were made on the basis of the linear sensitivity of the parental lines to the additive environmental variation, and  $F_2$ ,  $F_3$  and  $F_4$  generations derived from each of them. Both the linear and nonlinear components of the GE interactions of the advanced generation of each cross were related to the corresponding components of their parents. There was also evidence for the segregation of genes controlling these two components of the interaction in the  $F_3$  and  $F_4$  generations of the crosses between contrasting parents but not in those of crosses between similar parents. It is concluded that all aspects of the phenotype, including linear and nonlinear sensitivity to environment, are under genetic control and can be selected for in crosses between appropriately chosen parents.

Bedo and Balla (1977) determined adaptability of 16 varieties over 39 sites in 1974/75 and 43 sites in 1975/76, the estimates used being the mean yield ( $\bar{x}$ ) of a variety, the regression ( $b_i$ ) of the yield of a variety on mean yield of varieties over locations, and the error variance ( $\delta_i^2$ ) of the regression. Among high yielding varieties, Blueboy, Bezostaya 1 [Awnless 1] and Martonvasar 2 had good general adaptability, while Talent, Maris Huntsman and Maris Templar were classified as having special adaptability. The differences were particularly marked when the

results were analyzed separately for sites with above-average yields and sites with below-average yields.

In a seven-variety diallel cross excluding reciprocals, Bhullar *et al.* (1977) reported that the regression coefficients of the parents ranged from 0.66 in Sonalika to 1.34 in Kalyan Sona. The average value of the regression coefficient was lowest in the  $F_3$  and highest in the  $F_5$ . Phenotypic stability appeared to be associated with the genetic constitution of the parents as well as the heterozygosity and heterogeneity of the populations. There were distinct differences in general combining ability values for the regression coefficients among the parents. Data on yield and stability parameters showed that a high mean yield was not necessarily associated with average regression, indicating the possibility of combining high mean yield with high stability.

Luthra *et al.* (1977) presented analysis of the variance attributable to varieties, environments and GE interactions for grain yield, ears/plant, grains/ear, 1000-grain weight and plant height and the results of the study of stability parameters for two single, two double and two triple dwarfs and two tall varieties tested under 48 environments resulting from various combinations of nitrogen applications, spacing, and sowing dates. The varieties were divided into two groups with respect to yield response, a nonstable group comprising one single dwarf and the tall varieties, and a stable group comprising the remainder. Nonstability for yield in tall varieties was most likely due to nonstability for ears/plant and plant height. The pattern of stability for the triple dwarfs was different from that for the double dwarfs, the former being unstable for ears/plant. Grains/ear and 1000-grain weight were stable in all groups.

Chaudhary *et al.* (1978) studied GE interactions and the genetic architecture of harvest index by growing 21 homogeneous (varieties and  $F_1$ s) or heterogeneous ( $F_2$ s,  $F_3$ s and parental mixtures) populations at eight sites. Both the linear and nonlinear parts of GE interactions were important. There was no specific relationship between stability and homogeneity or heterogeneity, but certain parental populations, such as Hira and Kalyan Sona, their  $F_2$  and  $F_3$ , and mixtures involving them, had high stability, presumably owing to population buffering. Hira and Kalyan Sona also showed high harvest index and an average response and were regarded as promising. Components of genetic variance interacted with environment to a large extent. Harvest index proved to be governed by additive, dominance and epistatic gene effects.

Balla and Bedo (1979) analyzed the data on growth period of 16 varieties included in the 6th and 7th International Winter Wheat Performance Nursery (IWWP) tests (28 sites, 1973/74, 1974/75) and 16 varieties in the 7th and 8th IWWP tests (31 sites, 1974/75, 1975/76) using four methods. The material included early, mid-early and late varieties. Analysis of variance revealed no varietal differences in stability of growth period. With the Eberhart-Russell model, there was no varietal difference in regression coefficient but the regression error was less in earlier than in later varieties, indicating better adaptability in the former. Similar results were obtained with the Wricke's ecovalence model. A principal component analysis based on the Wricke's ecovalence values allowed varietal groups and the degree of divergence of individual varieties from their groups, to be distinguished. It

is concluded that growth period is a genetically determined character less satisfactory than yield for determining adaptability.

Ahmad *et al.* (1980) observed high GE interaction for grain yield, productive tillers and plant height. Non-linear component was high for grain yield and plant height.

Chaudhary and Paroda (1980) studied GE interaction for protein content in 21 genotypes of wheat in eight environments. The genotypes interacted significantly in the created environments at two locations. Artificially created environments at one location did not exhibit significant effect on protein content, whereas location effect was pronounced. Both the linear and non-linear components of GE interaction were found to be important. Some genotypes showed highly stable performance for protein content over environments.

Gill *et al.* (1980) reported that of 23 *Triticum durum* and two *T. aestivum* varieties grown at five sites in northern India, the durum wheat DWL5002, DWL5001 and Raj 1522 were the most stable varieties for yield performance.

Jatasra and Paroda (1980) found GE interaction for grain yield and its components in wheat. For grain yield, both the linear and non-linear components of GE interaction were significant and prediction of performance across the environments appeared to be difficult for the traits.

Srinivasulu and Majumder (1980) evaluated 17 varieties from a range of Indian sources under four environmental regimes (year x sowing date x water supply)

over two *rabi* seasons in the state of Manipur. K7411, K7510, HP1303, Sonalika, HP1327 and HP1102 proved suitable for growing in high-yielding environments. HD2233, K7402, HVW37 and HVW7 were suitable for use in medium-yielding drought-stressed environments and HVW26 and UP283 for growing in low-yielding drought-stressed environments.

Chaubey and Sastry (1981) investigated yield and six yield components of 11 Mexican and 14 Indian (Indo-Mexican derivative) varieties grown in four environments created by the application of different combinations of NPK and irrigation. No variety was stable for all characters but most were stable for number of days to flowering and ear number per plant. Varieties of moderate height were more stable than tall or dwarf varieties. Mexican varieties showed greater stability for grain yield per plant but Indian varieties gave higher mean yields. Ear number per plant had the greatest influence on yield.

Jatasra and Paroda (1981) performed genetic analysis on the parental,  $F_1$ ,  $F_2$  and  $F_3$  generations of four crosses between Indian and Mexican varieties of wheat. GE interactions were significant for height, tiller number, 100-grain weight and yield but not for ear emergence. The linear component appeared to account for most of the interactions present, indicating that mean performance for the varieties could be predicted across environments. With respect to grain yield, the  $F_1$ s were more responsive than 10 segregating generations. Genotypes with high mean values for plant height, tillers/plant and grain yield were, in general, more responsive to favourable environments.

Purohit *et al.* (1981) studied genetic variation, heritability, expected genetic advance and GE interaction for yield and five related characters in 25 lines under four sets of conditions. GE interactions were more important for grain yield and spikes/plant than for the other characters.

Heine and Weber (1982) calculated the stability parameters  $w_i$  (ecovalence),  $b_i$  (coefficient of linear regression) and  $S^2d_i$  (deviation from regression) using data from wheat trials over 20 years. None of these parameters was strongly correlated with yield. The  $w_i$  and  $S^2d_i$  were strongly correlated, indicating that it is unnecessary to calculate both. When the analysis was confirmed to control varieties which had been grown for many consecutive years, the parameters proved insufficiently consistent between years to warrant their use in assessing the stability of new varieties, considering that these are tested for a maximum of three years in official trials.

Jatasra and Paroda (1982) studied Mexican, Indian and their derivatives of wheat varieties under nine environments at three locations. Varieties of Mexican origin had the highest protein content under high fertility environments. PV 18, Larma Roho and UP 301 had high protein content and were stable.

Talukdar and Bains (1982) evaluated parental,  $F_1$  and  $F_2$  generations of an 8 x 8 diallel cross in four environments. GE interaction was evident for all ten characters studied. Linear and nonlinear components contributed towards interaction variances, but linearity predominated for grain yield, peduncle length, peduncle area, spike area and flag-leaf area. High stability for grain yield was shown by Kalyan Sona, WG377 and Sonalika. High x high stability crosses produced more stable progenies than did

high x low or low x low. Considerable reductions in the number of stable  $F_2$  progenies and reciprocal differences for stability in progeny performance were found. Tiller number and grains/spike were considered to be important for stability in yield.

Bhatia *et al.* (1983a) observed high GE interaction for grain yield, number of grains per spike, productive tillers, plant height and reproductive phase. The non-linear component was also significant in six traits and was highest for grains per spike.

Bhullar *et al.* (1983b) recorded data on grain yield/plant and five yield components for the eight diverse *Triticum durum* parents and 28  $F_1$ s from a diallel cross, without reciprocals, grown during 1978-79 at three sites in the Punjab. GE interactions were significant for all characters but no genotype was stable for all characters. Significant GE interaction was reported for grain yield, number of spikes per plant, number of grains per spike, 100-grain weight and spike length. For grain yield and spikes per plant, both the linear and non-linear components of GE interaction were significant but the non-linear component was of higher magnitude. MPO306 was the most adaptable genotype, exhibiting stability for grain yield, spikes/plant and 100-grain weight. Raj 1727 and HI9015 had low regression coefficients as well as non-significant mean square deviations. MPO306 x HI9015, MPO311 x HI9015 and MPO311 x HI9017 showed stability for yield.

Kumar *et al.* (1983) evaluated six parents (tall to triple dwarf), 15  $F_1$ s, 15  $F_2$ s and 15  $F_3$ s from a diallel cross, without reciprocals, grown in six environments for grain yield/plant and 5 yield-related characters. Both general combining ability

(GCA) and specific combining ability (SCA) variances had important effects on the traits studied, with the former predominating. GCA x environment variances were generally higher than SCA x environment variances. NP876, Sonalika and Kalyan Sona were good general combiners for grain yield and up to 4 of the other traits. Crosses involving good x good and good x poor combiners gave the greatest number of productive lines.

Nanda *et al.* (1983) tested 11 parents and 55  $F_1$ s from a diallel cross at three environments for four characters. Genotype x environment interaction was significant for all characters. Among the crosses, Kalyan Sona x WL410 was characterized by complete absence of genotype x environmental interaction. WG377 showed significant linear interaction for all characters and inclusion of this cultivar in hybridization programme is recommended.

Teich (1983) evaluated seven cultivars and 11 lines for yield at 16 localities in Ontario over two or three years. Genotype mean yields were regressed on locality-year mean yields and stability parameters (regression coefficient  $b$ , determination coefficient  $r^2$  and deviation from regression  $S^2d$ ) were determined. Cultivars had higher mean yields than lines and were also more stable. Selection for large  $b$  and  $r^2$  and small  $S^2d$  values, in addition to high yield, is recommended; a small  $b$  value is considered acceptable where mean yield is exceptionally high.

Malik and Rajpur (1984) recorded data on grains/spike, 100-grain weight and grain yield for eight indigenous and foreign cultivars grown under four fertilizer regimes (different N + P combinations). Values for all three traits were increased by

fertilizer application although the fertilizer doses themselves were regarded as non-significant. It is recommended that yield potential and adaptability be assessed under different environments before varietal release.

Rajput (1984) studied stability parameters in 68 advanced lines and reported significant differences among genotypes for plant height, productive tillers, grain yield, 1000-grain weight, protein content and phenol colour reaction. The non-linear component was observed significant for plant height, days to maturity, harvest index and protein content.

Of 18 genetically diverse varieties (including 4 of *Triticum durum*; 13 of *T. aestivum*) grown in six environments, Singh and Rana (1984) reported that Sonalika, HP916 and Janak, showing high mean yield, a lower regression value than unity and negligible deviation from regression, were the most promising for both normal and salt-affected soils. Arjun, WG377 and WL711 were suited to normal soils only. Kharchia 65 appeared to be adapted to alkaline and saline soils.

Mondal and Das (1985) used Eberhart and Russell model for stability analysis of yield/plant, 100-grain weight, height and days to maturity of 19 varieties grown in four environments. HD2270 was stable with respect to all four traits, while HD2285 was stable with respect to three traits.

A study of GE interaction effects conducted by Fox (1986) indicated that wide testing within years might not produce variability comparable with that produced between seasons. Environmental groupings within years showed neither regional basis nor did the groupings appeared repeatable between years. Regression models

did not account for the interaction. Homozygous cultivars interacted more with variable growing conditions than did unselected early generation bulks. The use of the relative performance of a reference set of genotypes to define a breeder's long term target population of environments was investigated by dividing a population of lines, grown at 18 locations for 2 years, into 2 equal random sets, one providing the reference set to determine weightings and the other a tester set to ascertain whether the weighted mean of the selection environments represented a simulated target better than the unweighted mean. Three weighting procedures were used. The first or error technique discarded environments with high coefficients of variation, the second involved canonical correlation, and the third technique was based on pattern analyses. Weighting effects were small. The error weighting technique was marginally successful, while the canonical correlation approach, which had been favoured on theoretical grounds and by its absence of arbitrary decisions, was unsuccessful. The pattern analysis approach to the weighting of selection environments appeared the most effective.

Kerkhi *et al.* (1987) reported stability parameters for eight physico-chemical attributes in 12 parents and their 66  $F_1$ s which were grown at three different agro-climatic conditions. The linear component of GE interaction was significant for grain yield and specific gravity. The variation due to non-linear component was highly significant for all the attributes except for grain yield.

Sharma *et al.* (1987) found that ten adapted genotypes at six Oklahoma sites over two years differed significantly for harvest index (HI) and grain yield, and significant genotype x environment interactions occurred for both traits. Estimates of

stability parameters indicated that all genotypes were unstable for both traits. Correlation coefficients between HI and grain yield were not consistent between good and poor environments. The results suggested that both traits are significantly affected by environmental changes, and hence that selection for yield per se might be as effective as selection for HI for improving grain yields in the diverse environments of the Southern Great Plains of the USA.

The *et al.* (1987) reported significant differences between environments and varieties and also for different traits when 24 varieties were evaluated on three different dates at two sites. No variety was stable for all the traits. HD2189, NI5439 and NI8635 gave high yields and had low regression coefficients, indicating their adaptability to poor environments. NI8625, with a moderate regression coefficient and high mean yield, was adaptable to a wide range of conditions, while RHR1336 and N59, with a high mean and a high regression coefficient, were suitable for favourable environmental conditions.

Kishore *et al.* (1988) found some stable genotypes in 60 advanced generation lines for tryptophan content, seed hardness and harvest index and also found that GE interaction, environment (linear) and nonlinear components were significant for all the traits.

Kumar and Ahmad (1988) found the linear component of interaction and linear component of environment to be significant for protein content, tryptophan content, seed hardness, 1000-grain weight and grain yield. The linearity was

predominant for protein content, 1000-grain weight, tryptophan content and grain yield.

Rasal *et al.* (1988) evaluated 24 wheat cultivars on three sowing dates at two locations to study the effect of environmental factors. There were significant differences between environments, cultivars and also for genotype x environment interaction. Among the cultivars studied, HD 2190, NI 5439 and NI 8635 produced high grain yield and low regression coefficient values showing their suitability for poor environments. NI 8625 with average regression coefficient value and high mean grain yield was adaptable for a wide range of environmental conditions.

Kumari *et al.* (1989) studied GE interaction effects for four yield components in 11 wheat varieties. The varieties differed in environmental responses affecting tillers/plant, grains/spike, test weight and seed yield/plant. Linear components contributed more strongly than non-linear components to all four characters, with heterogeneous populations being more buffered from environmental effects than homogeneous ones.

Soni *et al.* (1989) evaluated nine varieties of durum and 3 of bread wheat at 8 diverse locations and data recorded for grain yield/plot during 1983-84. Comparison of estimates of stability parameters, determined using Eberhart and Russell (1966) and Freeman and Perkins (1971) models, revealed a similar pattern of genotype regression coefficients. Only WL711 was shown to be stable with both models.

Jalaluddin and Harrison (1990) compared stability and response patterns for grain yield and test weight among 14 cultivars in 6 wheat performance trials in

Louisiana. Data were recorded on stability variance (SV), regression coefficient (RC), mean square for deviation from regression (MD), coefficient of determination (CD), variance of genotypic mean across environments (VE) and genotypic coefficient of variation across environments (GE). SV, MD and CD gave a similar ranking of cultivars for stability of grain yield or test weight, but rankings were not correlated between the two traits. Correlations of RC with VE and GE were higher for test weight than for grain yield. Since mean yield and mean test weight were as strongly correlated with each other as their regression responses, selection for high yield and test weight as well as high stability can be performed simultaneously by using regression parameters.

Mishra *et al.* (1990) presented the information on stability for grain yield and three of its components for 45 hybrids and their 10 parents under normal and late sowing at Rewa. Stability for grain yield was shown by Karazinho x Rewa 7-3, UP301 x Rewa 7-3, UP301 x K68 and Sharbati Sonora x K68.

More *et al.* (1990a) calculated coefficients of determination and ecovalence for 20 genotypes in seven environments in Maharashtra. The linear portion of the genotype-environment interaction was more significant than the non-linear portion implying that the response of a genotype to an environment is predictable. The genotypes NI5439, N8763, N59, AKW38-5 and MACS2159 were the most responsive and stable.

More *et al.* (1990b) evaluated grain yield of 20 genotypes at seven sites during rabi 1985-86. A significant GE interaction was observed. NI8629, NI8729, NI5439

and NI8796 were stable and adapted to all environments. It is suggested that the stability parameters are governed by an independent genetic system.

Saini and Gautam (1990) found GE interaction in segregating population of durum wheat. The differences among genotypes were highly significant for number of grains per ear, 1000-grain weight and plant height. The non-linear component of GE interaction was significant for yield per ear and 1000-grain weight.

Ahmad and Srivastava (1991) studied stability analysis of 56 F<sub>1</sub>s developed from 16 parents through partial diallel mating design at three locations. Pooled data revealed highly significant differences among the treatments for all the quality and physiological traits. The GE interaction was also significant for protein content, tryptophan content, seed hardness, number of productive tillers, spike length, seeds per spike, days to maturity and grain yield per plant.

Atale *et al.* (1991) estimated genotype-environment interactions for 9 genotypes grown in 6 environments during 1986-88. The most stable genotypes were AKW381, AKW405-1, AKW389-12 and WSM300 under late sown conditions.

Maloo (1991) reported highly significant mean squares due to genotypes, environment (linear) and GE interaction for plant height, productive tillers per plant, number of grains per spike, 1000-grain weight, grain yield per plant, biological yield per plant and harvest index. Both the linear and non-linear components of GE interaction were significant for all the traits. However, higher magnitude of non-linear component was for effective tillers and harvest index.

Manake *et al.* (1991) derived information on GE interactions from data on yield and three of its components in 18 genotypes grown during 1986-89 in five trials. The genotypes NI9629, NI9640 and NI9611 were considered the most stable.

Misra *et al.* (1991) evaluated four *T. aestivum* and 18 *T. durum* genotypes for the stability of four yield components when sown on three dates in 1985-86 and 1986-87. Results revealed that genotype x environment interaction occurred for all traits. Raj 1777 (*T. durum*) and K 65 (*T. aestivum*) produced the highest yields although the former was unstable and the latter was stable for yield over environments. None of the genotypes was stable for all the yield components studied; those with stability for individual traits are indicated.

Patil and Thakre (1991) evaluated ten genotypes in six environments. Hy 65 was the most stable genotype, and considered suitable for a wide range of environments, while BDN 500 gave a good yield in favourable environments.

Singh (1991) reported stability parameters from 54 advanced generation lines and six checks conducted at three diverse locations in Uttar Pradesh. Analysis of pooled data revealed that genotypes interacted significantly with environments for days to flowering, days to maturity, length of reproductive phase, number of productive tillers per m<sup>2</sup> 1000-grain weight, grain yield per plot, seed hardness and protein content. The non-linear component (pooled deviation) were observed significant for number of days to flowering, number of days to maturity, length of reproductive phase, number of productive tillers per m<sup>2</sup>, grain yield per plot, seed hardness, protein content and tryptophan content. Out of 54 advanced lines, B 341-

562, B 516, B 688, B 1153, B 1227 and B 1417-4 possessed better stability for grain yield and at least for two quality attributes. Advanced line B 1153 was stable for all the three quality traits in addition to productive tillers, 1000-grain weight and grain yield.

Srivastava and Ahmad (1991) observed highly significant interaction (linear) for number of productive tillers, days to maturity, 100-grain weight and grain yield. The linear component of environmental interaction was significant for grain yield, number of productive tillers, seed number per spike, days to maturity and 100-grain weight. The variation due to pooled deviation (non-linear) was highly significant for all the traits except for 100-grain weight indicating the substantial amount of genetic diversity in the material.

Baril (1992) used factor regression to partition the genotype-environment (GE) interaction into four biologically interpretable terms. Yield data were analyzed from 34 wheat genotypes grown in four environments using 12 auxiliary agronomic traits as genotypic and environmental covariates. Most of the GE interaction (91%) was explained by the combination of only three traits: 1000-grain weight, lodging susceptibility and spike length. As these traits are easily measured in breeding programmes the factor regression model can provide a convenient and useful prediction method of yield.

Kishor *et al.* (1992) analyzed stability for three yield components and three quality traits in 54 advanced generation lines and 6 standards of wheat grown at three locations. GE interaction, linear and nonlinear environment interaction components

were highly significant for all the traits. Twenty nine genotypes showed stable response for tryptophan content and 12 for seed hardness. Many genotypes also showed stability for protein content. Grain yield was positively correlated with 1000-grain weight and harvest index but negatively associated with protein, tryptophan content and seed hardness. Protein content showed positive association with tryptophan content and seed hardness.

Liu *et al.* (1992) analyzed the data obtained from a regional test of 14 hybrids and 10 pure lines over five locations in China using Eberhart-Russell's model and Shukla's method. Results showed significant genotype environment interaction for all characters and no differences between the effects on hybrids and pure lines. Hybrids were more stable for yield and their protein and dry gluten contents in favourable environments than pure lines. Hybrids involving high x high or high x average adaptive cultivars were generally superior in buffering ability. Significant correlation exists between the mean and stability parameters of wet gluten contents in hybrids, and synchrony exists between protein yield and grain yield stability for both hybrids and pure lines. It was suggested that the application of regression models for measuring the stability of the response of genotypes to various environments is effective and informative.

Mishra and Chandraker (1992) studied stability performance of grain yield for 10 late-sown wheat varieties grown at 5 locations in Madhya Pradesh during rabi 1984-85. The genotype x environment interaction was significant. Variety Swati, followed by HI1156, Sonalika and HI1116 showed stability across the environments. Variety HI1115 gave the best performance under favourable conditions.

Nachit *et al.* (1992a) employed AMMI model in the extensive multilocation testing data. Multilocation testing produced significant GE interaction that reduced the accuracy for estimating yield and selecting appropriate germplasm. The sum of squares (SS) of GE interaction was partitioned by linear regression techniques into joint, genotypic and environmental regressions, and by additive main effects and the multiplicative interactions (AMMI) model into five significant interaction principal component axes (IPCA). The AMMI model was more effective in partitioning the interaction SS than the linear regression technique. The SS contained in the AMMI model was six times higher than the SS for all three regressions.

Nachit *et al.* (1992b) reported the results of the Regional Durum Wheat (*Triticum durum*) Yield Trials for Low Rainfall areas (RYDT-LR) in which genotypes with differing morpho-physiological traits were grown in sites with diverse environmental conditions. Results of a previous study showed the effect of morpho-physiological traits of genotypes on GE interaction. The aim of this study was to identify the effect of intersite environmental variables on GE interaction. The additive main effects and multiplicative interaction (AMMI) model was used to study GE interaction. Site mean grain yields were significantly associated with environment first interaction principal component axis (IPCA1e). Site yields and IPCA1e scores were both associated with latitude, rainfall, irrigation, number of days with temperatures below freezing point, soil type and nitrogen fertilization. Altitude, nitrogen fertilization and weather index explained 79% of the site grain yield variability, while altitude and irrigation explained 66% of IPCA1e scores variability. Associations between site grain yields, environmental variables and IPCA1e reflected

site productivity. The association of AMMI multiplicative effects intersite environmental variables may improve understanding of GE interactions in the Mediterranean region.

Rajput and Ahmad (1992) studied stability parameters for six traits related to quality and productivity in a 11-parent diallel mating of macaroni wheat (*Triticum durum*). The genotypes interacted significantly with environment for all the characters. Non-linear components revealed highly significant differences for reproductive phase, seed hardness, protein and gluten content. The parents Jori C69 and Rai 911 showed higher stability for seed yield. Jori C69 was also stable for gluten content. Twenty  $F_1$  populations exhibited better stability for seed yield in comparison to their parents. Hybrids Meghdoot x WL1002 and NP404 x DWL5023 were stable for seed hardness, protein and gluten content.

Singh and Singh (1992) evaluated 36 wheat genotypes at eight locations under rainfed conditions during 1987-88. Mean grain yield was used to estimate different stability parameters. Pooled analysis of variance revealed variability among genotypes, environments and their interaction. Genotypes K8748, NDW20 and C306 were adaptable to poor environments, while HP1629-1, HUW354, RW481 and RW565 were suitable for favourable environments.

Jalaluddin and Harrison (1993) opined that stability statistics that are used to explain genotypic response to environments are not useful to plant breeders unless they are repeatable across sets of environments. The purpose of this study was to examine the repeatability of the stability estimators: regression coefficient ( $b_i$ ),

regression coefficient away from mean regression ( $b_i - 1$ ), mean squares for deviation from regression ( $S^2d_i$ ), Shukla's stability variance ( $\sigma_i^2$ ), variance of genotypic means ( $S_i^2$ ), and genotypic coefficient of variation ( $CV_i$ ), in addition to coefficient of determination ( $r_i^2$ ) and mean yield ( $X_i$ ). These statistics were calculated from three sets of yield data of the Louisiana Agricultural Experiment Station winter wheat performance trials grown in 36 environments. Repeatability was estimated by Spearman's rank-correlation coefficient and Kendall's coefficient of concordance. The  $b_i - 1$ ,  $\sigma_i^2$  and  $Sd_i^2$  were not repeatable between any two subsets of environments, and repeatability of  $S_i^2$  and  $r_i^2$ s were low. Among the stability estimators, only  $b_i$  and  $CV_i$  were repeatable across subsets of environments. The  $CV_i$  was not a reliable statistic to describe genotypic stability because the rank order of  $CV_i$  was induced by the rank order of  $X_i$ . Mean yield was the most repeatable genotypic character. Gain in selection for yield stability can be expected from the combined use of  $b_i$  and  $X_i$ . If data do not fit the linear regression model, then low values of  $S_i^2$  (Type 1) or Type 4 variance (variance of genotypic means across unpredictable environments averaged across predictable environments) may be used as an alternative criterion for yield stability.

Maloo *et al.* (1993) studied GE interaction for grain yield, biological yield and harvest index using 40 diverse wheat varieties/strains over nine environments created by sowing dates, fertilizer dose and irrigation levels in three successive years. GE interaction was significant for all the traits. Both linear and non-linear portions of GE interactions were significant for biological yield with predominance of linear component. Non-linear component was significant for grain yield and harvest index.

The mean performance appeared to be associated with linear response and stability for grain yield. HI747 and RCBD96 were the superior varieties identified in the present study.

Cooper *et al.* (1995) reported that selection for grain yield among wheat lines was complicated by large line-by-environment (LE) interactions in Queensland, Australia. Early generation selection is based on an evaluation of many lines in a few environments. The small sample of environments, together with the large LE interaction, reduced the realized response to selection. Definition of a series of managed-environments which provides discrimination among lines, which is relevant to the target production-environments, and can be repeated over years, would facilitate early generation selection. Two series of managed-environments were conducted. Eighteen managed-environments were generated in series-1 by manipulating nitrogen and water availability, together with the sowing date, at 3 locations. Nine managed-environments based on those from series-1 were generated in series-2. Line discrimination for grain yield in the managed-environments was compared to that in a series of 16 random production-environments. The genetic correlation between line discrimination in the managed-environments and that in the production-environments was influenced by the number and combination of managed-environments. Two managed-environment selection regimes, which gave a high genetic correlation in both series-1 and 2, were identified. The first used 3 managed-environments, a high input (low water and nitrogen stress) environment with early sowing at 3 locations. The second used 6 managed-environments, a combination of a high input (low water and nitrogen stress) and medium input (water

and nitrogen stress) with early sowing at 3 locations. The opportunities for using managed-environments to provide more reliable selection among lines in the Queensland wheat breeding programme and its potential limitations are discussed.

Kheiralla and Ismail (1995) evaluated 10 wheat cultivars of diverse origin for grain yield and some traits related to drought resistance over 12 environments (developed by combinations of 2 seasons, 2 levels of soil moisture and 3 rates of N fertilizer) during 1992-94. Low soil moisture caused significant reduction in water content of excised leaves and grain yield/fed [1 feddan = 4200 m<sup>2</sup>]. Increasing N rate led to increased days to heading, leaf water loss percentage and grain yield. Highly significant GE interactions were found for days to heading, leaf-water loss percentage and grain yield. The major component of differences in stability was due to the linear regression for the studied traits. The regression coefficient was positively correlated with the mean performance, indicating that low yielding genotypes were generally stable while high yielding ones were rather responsive. However, Giza 160 exhibited stability for high grain yield and low leaf water loss percentage, whereas Sakha 92 was stable for high grain yield and days to heading.

Singh *et al.* (1995) evaluated 90 progenies produced by crossing 30 wheat varieties/lines with three testers in a triple test-cross fashion to detect various components of genetic variation and interaction of these components with sowing date for seven metric traits. The testers were adequate for days to heading, grain number, 1000-grain weight and grain yield per plant. Epistasis was observed for plant height, tiller number and spike length in both sowings. The non-fixable epistasis was more important and sensitive to environment than fixable epistasis. Generally, the

additive component was equally or more important than the dominance component. Both the components were equally sensitive to the change in environment. In all cases, dominance was directional. •

Annicchiarico and Mariani (1996) assessed adaptability, yield stability and yield reliability of durum wheat breeding lines through regional testing. The opportunity of partially substituting such testing by evaluation under normal and artificially drought-stressed rainfed conditions was investigated for a water-limited Italian region. Nine lines were grown at six sites for three seasons to assess adaptability across locations as Perkins and Jinks' slope of genotype regressions ( $\beta$ ), stability across environments as Shukla's stability variance ( $\sigma^2$ ), mean yield ( $Y$ ), and Eskridge's reliability ( $R$ ) from  $Y$  plus  $\sigma^2$ . Heterogeneity of genotype regressions explained 54% of genotype-location interaction variation. The  $\beta$  values were strictly associated ( $r=-0.99$ ) with genotype scores on the first genotype-location interaction principal component (PC1), were not related to earliness of heading, and tended to negative correlation with plant stature that was hardly explainable in terms of resistance to lodging. Mean yield, PC1 score and rainfall of sites were correlated. The lines were also grown under normal and stress conditions at four sites for two seasons. The stress was established by placing metal channels between the rows that evacuated a portion of rainfall from the end of tillering stage onwards. Predictions of  $\beta$ ,  $\sigma^2$ ,  $Y$  and  $R$ , attempted respectively from slope of genotype-stress level interaction ( $\beta P$ ),  $\beta P^2$ , mean yield across conditions ( $Y P$ ), and  $Y P$  plus  $\beta P^2$ , were assessed as genetic correlation. Predictions based on  $\beta P$  and  $Y P$  computed over all test environments were all relatively good, whilst those based on data of individual

seasons or locations were mostly inaccurate for  $\sigma^2$ , Y and R. High-yielding sites could better predict Y and R. Two seasons' data from one such site showed correlations of 0.60, 0.53, 0.72 and 0.75 for prediction respectively of  $\beta$ ,  $\sigma^2$ , Y and R. Evaluation of advanced breeding lines under normal and artificially stressed conditions at a high-yielding site may prove useful for reducing the number of lines promoted to subsequent regional testing and/or restricting their regional testing to specific areas of adaptation.

Deswal *et al.* (1996) evaluated 35 genotypes of bread wheat (*Triticum aestivum*) and three of macaroni wheat (*T. durum*) for harvest index, plant height, number of tillers/30 cm, grain weight/spike and 1000-grain weight at Karnal, Haryana during rabi 1994-95 under three environments (timely sown, high fertility and irrigated; timely sown, low fertility and rainfed; and late-sown, high fertility and irrigated). Significant GE interactions were observed for plant height, number of tillers/30 cm and grain weight/spike. Both predictable and unpredictable components shared the GE interaction for plant height and number of tillers/30 cm. However, for grain weight/spike, the non-linear component was predominant. In spite of non-significant GE interactions, the linear component was significant for 1000-grain weight. No GE interactions were observed for 1000-grain weight and harvest index. A majority of genotypes were stable for different traits.

Ishag and Mohamed (1996) grew five wheat cultivars in early Nov., late Nov. or mid-Dec on heavy clay (Vertisol) in 1990-91 in central Sudan. Duration of phenological stages was affected by cultivars and sowing dates. Total thermal units for the full cycle of these wheats were 2390 ( $^{\circ}\text{C day}$ ). Grain weight was negatively

correlated with mean air temperature during grain filling ( $r=-0.83^{**}$ ) with an increase of  $1^{\circ}\text{C}$  causing a decrease of 4 mg in grain weight. It was suggested that the best plan for such a hot environment is to sow late-maturing cultivars early in the season, and to sow early-maturing cultivars late, so that spike emergence coincides with the coolest period. The cultivar x environment interaction was significant for grains/spike, grain weight and yield. The cultivar El Neilein was consistently high yielding and more stable, by several indices, across environments.

Kara (1996) used data on grain yield of 8 bread wheat genotypes grown in 5 environments to assess the effectiveness of different stability statistics in measuring stability of genotypes. The estimates of stability statistics varied with genotypes, indicating marked stability differences among genotypes. None of the statistics was significantly correlated with mean yield. The  $S_i^2$  and  $CV_i$  statistics were highly correlated with each other as well as with  $b_i$ . The relative rankings of the genotypes for  $W_i^2$  and  $\sigma_i^2$  were exactly the same.

Menon and Sharma (1996) carried out stability analysis of grain yield and associated traits using the parental and  $F_2$  generations of a 10 x 10 diallel cross of bread wheat (*Triticum aestivum*) over six environments created by three different sowing dates at two locations. The environment linear component was highly significant for all the traits studied. However, the genotype x environment linear component was significant only for grain yield, number of grains per spike and flag leaf area. All the five yield components under study varied in a compensatory fashion to impart homeostasis to the final and complex character of yield. The varieties HD2204 and Raj1482 and the crosses Kharchia 65 X HD2204 and Brochis X

Raj1482 expressed high performance and stability for grain yield, and could be useful in the development of new genotypes through hybridization.

Bhavsar *et al.* (1996a) tested 14 genotypes of bread wheat at 12 locations in Karnataka and Maharashtra for grain yield. Mean differences between genotypes and environments were highly significant, indicating substantial variability among genotypes and environments. GE interaction was significant. Both linear and non-linear components of GE interaction played an important role in the expression of grain yield. The genotypes NI9947 and DL802-3 were the most stable for grain yield. AKW619 and AKW2294 were adaptable to all types of environments, while NIAW34 was stable under favourable environmental conditions.

Bhavsar *et al.* (1996b) evaluated 20 genotypes of *Triticum aestivum* and *T. durum* for stability of grain yield over ten environments in Karnataka and Maharashtra. Significant GE interaction was observed for the character. Both linear and non-linear components of GE interaction were significant, although the linear component was larger in magnitude. The genotypes N5439, NIAW60 and DWR2005 were suitable under moisture stress conditions. None of the genotypes was superior over all ten environments.

Awaad (1997) evaluated six durum wheat [*Triticum durum*] genotypes for 8 yield-related traits at sowing densities of 50, 70 and 90 kg seeds/fed at Zagazig (clay soil) and Khattara (sandy soil) during the winter seasons of 1994-1996. Location, sowing rates, year and genotypes contributed 39.1, 16.4, 13.1 and 12.5% to total

variance, respectively. The exotic Om Rabi 3 and local variety Sohag 2 were most stable in all environments.

Kara (1997) tested 12 bread wheat (*Triticum aestivum*) genotypes in the Central Black Sea Region of Turkey (3 locations in 1987 and at 2 locations in 1998) to evaluate different stability parameters and rank correlations among them. From the information on mean yield and comparative stability parameters, Kate A1 was judged as the most stable genotype. The mean yield was significantly correlated only with coefficient of determination ( $r^2_i$ ). The linear regression ( $b_i$ ) statistic showed significant positive correlation with  $r^2_i$ , genotype variance ( $S^2_i$ ) and coefficient of variability ( $CV_i$ ). The ecovalence stability index ( $W^2_i$ ) and stability variance ( $\sigma^2_i$ ) were perfectly correlated ( $r = 1.00$ ) and the relative rankings of cultivars for the two parameters were exactly the same. The  $S^2_i$  and  $CV_i$  statistics rank correlated well with each other.

Menon and Sharma (1997) studied phenotypic stability in 55 genotypes of hexaploid wheat (45  $F_2$  and 10 parents) grown over 6 different environments for days to maturity, plant height, tiller number, 1000-grain weight, harvest index and grain yield. The environment linear component was highly significant only for grain yield, tiller number and plant height. The most stable for grain yield were HD2204, Brochis x Raj 1482 and Kharchia 65 x HD2204.

Robert (1997) studied the structure of genotype x environment interaction in two series of trials for three quality traits in bread wheat. Two kinds of environments were present in each series of trials: macro-environments defined as locations or

location x year combinations and micro-environments induced by diversified cultural practices within each site. For each trait, a simultaneous clustering procedure was used to identify groups of environments which were homogeneous for interaction. An optimized series of trials was proposed from the clusters obtained. The cultural practice based on nitrogen fertilization seemed to better diversify environments for interaction than use of fungicide, when all quality traits were considered. Determining an optimized series of trials simultaneously for the three traits led to keeping more environments than when one trait was considered. Suggestions for establishing a series of trials for a multi-trait analysis were proposed.

Sarma *et al.* (1997) evaluated 48 triple test cross families and 16 varieties/lines of spring wheat in high fertility and medium fertility environments to detect and measure the interactions between the environments and the additive, dominance and epistatic effects of the genes for yield and its component traits. Epistasis was important for all the traits. The additive gene effects were more sensitive to environmental change than dominance gene effects. The j and l type epistasis was relatively more sensitive to environmental differences than the i type epistasis.

Swati *et al.* (1997) studied stability of 15 wheat genotypes at two different locations differing in soil type, soil fertility and climatic conditions. The GE interaction for seed yield was measured by mean grain yield, genotypic variance ( $s_i^2$ ), coefficient of variation ( $cv_i$ ), and ecovalence ( $w_i^2$ ). Only mean performance was used to evaluate plant height, time to flowering and 1000-grain weight. Most of the genotypes showed stability for plant height, heading and 1000-grain weight. Barani-

83 and Lu-26 with high mean yield, least ecovalence, genotypic variance and coefficient of variation values appeared to be the most stable genotypes. Khyber-87 and Pirsabak-85 had unfavourable genotypic variance, ecovalence, and coefficient of variation but highest mean yields across the locations, and were therefore included among the stable genotypes.

Uzik and Krajewski (1997) compared methods for variety classification according to response to irrigation (Z), nitrogen (N) and phosphorus (P). In a greenhouse experiment, 9 wheat varieties released between 1923 and 1995 were tested at 3 levels of Z, N and P. Regression coefficients, sums of squares of deviations from regression and ecovalence were estimated. For variety and environment classification, factor analysis was used. The response of varieties to Z, N and P was characterized by calculating square roots of variance components obtained from an analysis of variance made for each variety independently. Older varieties had higher regression coefficients on environments and higher variance components for Z, N and P than modern ones because modern varieties were more tolerant of stress. According to factor analysis, modern varieties had higher genetic diversity than old ones.

Badhe *et al.* (1998) evaluated 21 varieties of wheat along with four checks at six locations for grain yield, 1000-grain weight and days to 50% heading. Mean differences between genotypes and environments were highly significant indicating substantial variability among genotypes and environments for all characters. Highly significant variance due to environment + (genotype x environment) revealed that genotypes interacted considerably with environmental conditions that existed at different locations. Significant genotype x environment interaction was observed

except for grain yield. Both linear and nonlinear components of genotype x environment interaction played an important role in the expression of these characters. However, the nonlinear component was larger in magnitude. It was observed that NIAW 163 and NIAW 158 were adaptable to all environments, while the genotypes NI 9947, NIAW 168 and NIDW 3 were suitable for rich environmental conditions.

Farshadfar *et al.* (1999) investigated the genetic properties of different types of stability parameters for individual genotypes using an eight-parent half-diallel cross in a randomized complete block design with three replications. Data pertaining to the parents and F1s were subjected to Griffing and Hayman methods for the genetic analysis of eight types of stability statistics. The results of analysis of variance showed that genetic variation existed for almost all the stability parameters. Moderate heritability estimates were observed for coefficient of variation ( $CV_i$ ) and superiority measure ( $P_i$ ). The estimates of variance components suggested that genes controlling environmental variance ( $S^2_i$ ), regression coefficient ( $b_i$ ), ecovalence ( $W^2_i$ ) and  $P_i$  are predominantly additive, while non-additive gene action was predominant for  $CV_i$ , stability variance ( $\sigma^2_i$ ) and coefficient of determination ( $R^2_i$ ). The results of combining ability effects indicated that the best general combiners for the improvement of adaptation were Chinese Spring and Shakha, while the best stable specific combination was Shakha/Kobomugi.

Kara (1999) opined that GE interactions, in particular leading to different rankings of the genotypes in variable environments, are a major challenge to plant breeders. Numerous methods of characterizing stability of genotypes across

environments are available. The objectives of this investigation were to study non-parametric measures of stability based on the ranks of genotypes in different environments and simultaneous evaluation of yield and yield stability by means of Huhn's  $S_i(1)$ ,  $S_i(2)$ ,  $S_i(3)$ ,  $S_i(6)$ , Jensen's  $H_i(5)$  statistics and two indices. The indices were derived from the sum of the two ranks;  $X_i$  rank +  $W_i^2$  rank, and  $r_i$  +  $S_i(2)$  rank, respectively. The data used in estimating these statistics were obtained from the Official Winter Bread Wheat Registration Trials with 15 genotypes tested at 13 environments (year-location combinations). The  $S_i(1)$  and  $S_i(2)$  statistics selected higher yielding genotypes. The  $S_i(3)$  and  $S_i(6)$  statistics, however, appeared to give more weight to stability than did  $S_i(1)$  and  $S_i(2)$ . Rank correlation coefficients indicated that low  $S_i(3)$ ,  $S_i(6)$ , and  $W_i^2$  were generally associated with low yield. Jensen's  $H_i(5)$  statistic and Index 2 (sum of mean rank ( $r_i$ ) and  $S_i(2)$  rank) showed a high degree of association with yield. Repeatability of stability statistics were studied by measuring rank correlations between high-yield and low-yield environments. The repeatability of Index between high-yield and low-yield environments was relatively high and significant. Repeatability of the other statistics between the two groups of environments was negligible.

Maloo *et al.* (1999) reported stability parameters for grain protein content for 21 genotypes of *Triticum aestivum* and 19 genotypes of *T. durum* grown under 3 dates of sowing for 3 successive years at variable irrigation levels and fertilizer dose, creating a total of 9 environments. Genotype environment interactions were highly significant. Genotypes Raj 911, PON2, Malavaraj, Malvika, C306 and MP820 expressed high grain protein percentages and were adapted to high-yielding

environments. MP806 showed stability under low management conditions and P6190 displayed wide adaptability. Of these eight genotypes identified as stable, five (Raj 911, PON2, Malavaraj, Malvika, P6190) were durum types.

Kara (2000) used data on grain yields of 15 bread wheat (*Triticum aestivum*) genotypes grown at 8 locations to assess adaptation and stability characteristics of the genotypes and to study associations among yield parameters. According to most of the parameters used in the study, Kirac 66, Es-kbvd-15 and Ank-92-1 appeared to have a good level of general adaptation to all environments. Mean yield was highly correlated with  $S_i^2$ ,  $b_i$ ,  $\alpha_i$  and  $\beta_i$ . The regression coefficients  $b_i$ ,  $\alpha_i$  and  $\beta_i$  were perfectly rank correlated ( $r = 1.00$ ) with each other as well as with  $S_i^2$  and  $CV_i$ . Eberhart and Russell's  $Sd_i^2$  statistic was highly associated ( $r = 0.93$ ) with Tai's  $\lambda_i$ . The stability statistics  $S_i(2)$  and  $S_i(3)$  of Huhn showed good rank correlation with  $CV_i$ ,  $W_i^2$  and  $Sd_i^2$ . The statistics based on the ranks of genotypes over environments, such as  $S_i(2)$  and  $S_i(3)$ , could be potential alternatives to the parametric approaches currently used.

Mishra *et al.* (2000) studied eight promising wheat genotypes (GW 190, DL 803-3, Raj 1555, WH 147, HI 1077, HI 8381, DL 788-2 and WH 533) during 1996-97 and 1997-98 on three different dates (normal, 22 November; late, 2 December; and very late, 12 December). The results showed that DL 788-2 and GW 190 had higher adaptability and stability, and may be recommended for normal and late sowing conditions. The cultivar WH 147 was responsive to rich environments and may be recommended for cultivation based on normal sowing dates. DL 803-3 and Raj 1555 showed stability and sustainability under poor environmental conditions and might be recommended for cultivation under late sowing conditions.

Purchase *et al.* (2000) evaluated 13 winter and intermediate type bread wheat cultivars for yield stability under dryland conditions over a four year period from 1991 to 1994 and over a total of 120 environments in the Western, Central and Eastern Free State wheat producing regions of South Africa. The following statistical analyses were conducted and procedures followed to determine yield stability: (i) Shukla's procedure of stability variance ( $\sigma^2_i$ ); (ii) Lin and Bins cultivar performance measure ( $P_i$ ); (iii) Finlay and Wilkinson's regression analysis and coefficient ( $b$ ); (iv) Eberhart and Russell's deviation from regression ( $S^2_d$ ); (v) Wricke's ecovalence ( $W_i$ ); (vi) AMMI model. Since the AMMI model does not make provision for a quantitative stability measure, such a measure was developed to rank genotypes. Total correspondence for significance of Spearman's rank correlation coefficients for the different analysis procedures was noted over the three production regions. No significant rank correlation coefficients were found in the pair-wise comparisons of both Lin and Bins' and Finlay and Wilkinson's procedures with the other procedures, nor in the comparison between the two mentioned procedures. This indicates that the Lin and Bins procedure, as well as the Finlay and Wilkinson procedure, differ significantly from the other procedures in stability determination and definition, and due to noted deficiencies are consequently not recommended for use. From the study it would appear that if a single method of describing the stability of a genotype had to be selected, the proposed AMMI Stability Value (ASV) AMMI model would be the most appropriate. Certain cultivars showed similar stability over the three regions, while others varied considerably over the three regions.

Sial *et al.* (2000) studied the stability for yield performance and GE interaction in 12 wheat (*Triticum aestivum*) genotypes grown at 13 contrasting sites (12 in Sindh and one in NWFP) over two years. The combined analysis of variance over all environments revealed a highly significant difference for genotypes, environments and GE interaction. An adaptation analysis was applied to estimate the b, s.e. (b) and deviation from regression coefficients ( $S^2d$ ) for each genotype. Genotype SI90157 produced the highest mean yield over all environments, showing wide adaptation and stability. Genotypes PN90111, Anmol 91, SP89126 and SH8921 gave the lower mean yield over all environments with high value of s.e. (b) and  $S^2d$ . SI88126 gave higher yield in high yielding environments, showing weak stability. The utilization of stable genotype SI90157 in breeding for high yield is suggested.

Madariya *et al.* (2001) evaluated 50 wheat genotypes in Junagadh, Gujarat, India, during the rabi season of 1994-95 for stability parameters with respect to grain yield and its component characters (number of effective tillers per plant, number of spikelets per spike, number of grains per main spike, and 1000-grain weight) under three sowing conditions (early-29 October; timely-15 November; and late-2 December). Linear and nonlinear components of genotype environment interaction were significant for grain yield per plant, number of spikelets per spike, number of grains per main spike and 1000-grain weight. For the number of effective tillers per plant, only the linear component was significant. Only JAB-95-7 was stable for all characters. JAB-95-16, JAB-95-23, JAB-95-27, JAB-95-31, JAB-95-33, and JAB-95-7 were superior due to their high yield and stability for grain yield. The number of

effective tillers per plant, number of spikelets per spike, number of grains per main spike, and 1000-grain weight were the major yield components.

Ortiz *et al.* (2001) reported that several genotype-by-environment stability measures are in use, but little information exists about their inheritance or genetic interrelationships. Among those measures in common use are the linear regression coefficient ( $b$ ), deviations from regression ( $sb$ ), coefficient of determination ( $R^2$ ), coefficient of phenotypic variation (CPV) and, more recently, interaction principal components (IPCA) of the additive main effect and multiplication interaction (AMMI) model. Because of the factorial structure of the data, the diallel cross is well suited to study these parameters and their relationship to quantitative traits. For this study a complete diallel cross, derived by mating eight lines (Buri, Kenya Chiruku, Edsa\Lira, Vee "S", Atilla, CY8801, F6603147 and Car853) from a broad based bread wheat breeding population, was grown for several seasons at two Ugandan locations (Kalengyere and Buginyanya), one of which was prone to yellow rust [*Puccinia striiformis*]. Stability parameters and grain yield were measured for each cross. CPV had the highest narrow-sense heritability ( $h^2=0.522$ ) followed by IPCA1 of the AMMI ( $h^2=0.461$ ). Lowest narrow-sense heritabilities were calculated for  $b$  and  $R^2$  ( $h^2=0.150$  and  $0.100$  respectively). There were high additive genetic correlations ( $r_A$ ) between grain yield and CPV ( $r_A=-0.933$ ), grain yield and IPCA1 ( $r_A=0.707$ ), and grain yield and IPCA2 ( $r_A=0.751$ ). The genetic association between CPV and IPCA1 was also high and negative ( $r_A=-0.934$ ). These results suggest that it may be possible to select simultaneously for high and stable grain yield in this broad-based bread wheat breeding pool by selecting outyielders that exhibit a low CPV.

Yan and Hunt (2001) opined that an understanding of the causes of GE interaction can help identify traits that contribute to better cultivar performance and environments that facilitate cultivar evaluation. Through subjecting environment-centered yield of a multi-environment trial data to singular value decomposition, the portion of yield variation that is relevant to cultivar evaluation is partitioned into non-crossover and crossover GE interaction, quantified by the first two principal components (PC), respectively. Each PC is a set of genotypic scores multiplied by a set of environmental scores. By relating the PC scores to genotypic and environmental covariates, GE interaction represented by each PC can be interpreted in terms of trait x factor interactions. This strategy was employed in analysis of the 1992 to 1998 Ontario (Canada) winter wheat (*Triticum aestivum*) performance trial data. Results indicated that plant height and maturity were the major genotypic causes of GE interaction, whereas cold temperature in the winter and hot temperature in the summer were the major environmental causes of GE interaction. Positive interactions were found between earlier maturity vs. warmer winters or hotter summers, and between shorter plant height vs. warmer winters or cooler summers. In addition, better resistance to septoria leaf blotch caused by *Septoria secalis* was frequently associated with overall performance. The results of this study should help in determining breeding objectives and for selecting test sites or environments for winter wheat breeding in Ontario.

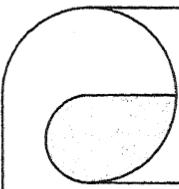
Mondal and Khajuria (2002) evaluated 10 wheat cultivars (HB 208, HD 2329, HD 2380, HD 2428, HS 240, IWP 72, Kundan, PBW 175, VL 614 and VL 616) for stability in Jammu and Kashmir, India from 1992-93 to 1995-96. The results

indicated significant genetic variation in terms of GE interaction for yield and other characters. HS 240, HD 2380 and PBW 175 were high yielding, stable cultivars and produced higher yields than the others in unfavourable years. Kundan and HD 2428 were below average in performance in unfavourable years. HD 2329 and HD 2428 were below average in performance, and HB 208 and VL 616 had average performance, but were unstable, over the environments.

Robert (2002) evaluated stability and genotypic mean of four traits, grain yield, grain protein content, alveograph W and bread volume in three multi-location trials, each covering two years. The stability of each genotype was evaluated by environmental variance ( $s^2E$ ), interaction variance ( $s^2W$ ) and variance of the ranks of the phenotypic values corrected for the genotypic effect ( $s^2R$ ). The bootstrap method was used to study correlations between the genotypic mean and the three stability statistics and to calculate their accuracy. The repeatability of the stability statistics was measured by correlations between the values obtained in each of the two years. In addition, theoretical smaller trials were generated by random sampling and the stability values calculated were correlated with those of the original trial. Environmental variance appears to be usable both for yield and for quality traits, but there is a risk of counter-selecting a high genotypic mean of W. Whatever the trait and statistic envisaged, stability is poorly repeatable and its evaluation requires several years and a large number of locations per year to minimize sampling and environmental effects.

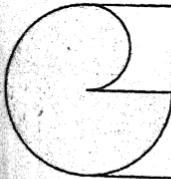
Singh *et al.* (2002) evaluated stability of 10 characters of 21 advanced selections of bread wheat in a field experiment conducted in Uttar Pradesh, India

during the rabi seasons of 1994-95. Mean differences between genotypes and GE interaction were highly significant for all the characters. The average performance of the genotypes with respect to grain yield and yield attributes varied significantly. The linear component (environment) of interaction was significant for all the traits. High magnitude of environmental effects in the genotype x environment interaction was recorded. Variances due to pooled deviation were significant for 6 characters, indicating a considerable genetic diversity among the advanced selections. Non-linear deviations were also significant for all the traits examined. Regression coefficient analysis showed that eight advanced selections were stable for the characters examined under favourable environments.



Chapter 3

**MATERIALS AND METHODS**



## MATERIALS AND METHODS

Twenty five promising genotypes of wheat (*Triticum aestivum* Linn. Em. Thell.) were selected for the present study. These varieties namely, UP 2472, NW 1014, PBW 466, HUW 520, K 8027, HD 2733, NW 1012, PBW 450, UP 2003, HD 2285, NW 1076, HUW 516, HP 1838, K 9545, HP 1761, K 9170, PBW 443, K 9533, C 306, HP 1744, K 8962, HUW 234, HP 1731, HP 2743 and PBW 473 are the advanced breeding lines and were collected from the genetic stocks maintained in the section of Economic Botanist (Rabi-cereals), Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh.

During Rabi 2001-02, all the 25 genotypes were sown in a Randomized Complete Block Design with three replications under artificially created six environments. The environments were created by sowing genotypes under normal and late conditions with three regimes of fertilizers *i.e.*, recommended dose of fertilizer, 50% of the recommended dose of fertilizer and without fertilizer application. Normal sown crop was planted on 13 November 2001 while late sown crop was planted on 30 December 2001. Recommended dose of fertilizer contained 100 kg nitrogen, 60 kg phosphorus and 40 kg potash while 50% recommended dose of fertilizer included 50 kg nitrogen, 30 kg phosphorus and 20 kg potash. Each genotype was sown in six-row plot by dibbling method under each environment. Non-experimental rows were also kept to check the border effect. The length of each row was 4 m with inter and intra-row spacings of 25 cm and 15 cm, respectively. All the plots were given five irrigations at different stages of crop development along

with other usual agronomic practices to raise a successful crop. The treatments were harvested as and when they were matured.

From the above experiment, data on 10 traits were recorded in each environment for stability analysis. The plants used for observations were tagged after 50 days of sowing. The data were recorded on randomly taken five plants from each genotype in each environment for the traits as mentioned below:

1. **Days to 50% heading:** Days from sowing to appearance of heads in 50% of the plants in the plot was taken as days to 50% heading.
2. **Days to maturity:** Days from sowing to maturity of grains in a plot was taken as days to maturity.
3. **Length of reproductive phase (Grain filling period):** Days from flowering to maturity were calculated for the length of reproductive phase.
4. **Plant height:** The height of main shoot was recorded in centimeter from the base of plant to the top of the panicle excluding awns at the time of maturity.
5. **Number of productive tillers per plant:** Total number of ear bearing tillers per plant was counted before harvesting.
6. **Panicle length:** The length of spike was recorded in centimeter from the base of panicle to the top of panicle excluding awns.
7. **Number of seeds per panicle:** The total number of seeds per main spike was counted.

8. **100-seed weight:** Hundred seeds were sampled three times at random from the bulk harvest of each progeny and from each replication separately and their weight was recorded in gram up to second decimal place in a Metler balance. Mean of these samples was taken as final reading for the trait.
9. **Harvest index:** Grain yield divided by biological yield of the plant and multiplied by 100 was considered as harvest index in percentage.
10. **Grain yield per plant:** The weight of the grains per plant was recorded in gram up to the second place of decimal on a Metler balance.

### **Statistical Analysis**

The experimental data were compiled by taking mean of each treatment for all the replications for each environment, then pooled and were then subjected to the following statistical and biometrical procedures:

- Finlay and Wilkinson model (1963)
- Eberhart and Russell model (1966)
- Perkins and Jinks model (1968a)
- Freeman and Perkins model (1971)

## Analysis of Variance for the Experiment

The analysis of variance for the experimental design is based on the following model;

$$P_{ijk} = \mu + g_{ij} + r_k + e_{ijk}$$

$$(i, j = 1 \dots t; k = 1 \dots r)$$

where,

$P_{ijk}$  = phenotype of  $ijk^{\text{th}}$  observation

$\mu$  = population mean

$g_{ij}$  = genotype effect

$r_k$  = the effect of  $k^{\text{th}}$  replication

$e_{ijk}$  = the error for  $e_{ijk}^{\text{th}}$  observation

On this model, the data obtained from the present investigation were first subjected environment-wise to the randomized complete block design analysis on the mean basis. The skeleton of ANOVA table is given under:

Source of variation	d.f.	Mean square	F test
Replications	(r-1)	Mr	Mr/Me for (r-1) and (r-1) (t-1) d.f.
Genotypes	(t-1)	Mt	Mt/Me for (t-1) and (r-1) (t-1) d.f.
Error	(r-1) (t-1)	Me	

Similarly, the skeleton for pooled over the environments is given as follows:

Source of variation	d.f.	Mean square	F test
Environment (E)	(e-1)	$M_e$	$M_e/M_{ep}$ for (e-1) and (e-1)(r-1)(t-1) d.f
Replications (R)	(r-1)	$M_r$	$M_r/M_{ep}$ for (r-1) and (e-1)(r-1)(t-1) d.f.
E x R	(e-1) (r-1)	$M_{lr}$	$M_{lr}/M_{ep}$ for (e-1) (r-1) and (e-1)(r-1)(t-1) d.f.
Genotypes (G)	(t-1)	$M_t$	$M_t/M_{ep}$ for (t-1) and (e-1)(r-1)(t-1) d.f.
G x E	(t-1)(e-1)	$M_{te}$	$M_{te}/M_{ep}$ for (t-1)(e-1) and (e-1)(r-1)(t-1) d.f.
Error	(r-1) (t-1)	$M_{ep}$	

### Eberhart and Russell Model (1966)

The phenotypic stability of genotypes under different environments was carried out following Eberhart and Russell, which is based on the following model:

$$Y_{ij} = m_i + b_i I_j + s_{ij}$$

Where,

$Y_{ij}$  = mean of the  $i^{\text{th}}$  genotype at  $j^{\text{th}}$  environment ( $i=1, 2, \dots, t$ ) and  $j = 1, 2, \dots, s$ )

$m_i$  = mean of the  $i^{\text{th}}$  genotype over all the environment

$b_i$  = regression coefficient which measures the response of the  $i^{\text{th}}$  genotype to the varying environments

$I_j$  = environment index = mean of all genotypes at  $j^{\text{th}}$  environment – grand mean

$$= x_j - s \dots$$

$s_{ij}$  = deviation from regression of the  $i^{\text{th}}$  genotype at the  $j^{\text{th}}$  environment

Regression coefficient, the first stability parameter, is estimated as under:

$$b_i = \sum Y_{ij} I_j / \sum I_j^2$$

The performance of each genotype can be predicted by using the estimates of parameters as given below:

$$Y_{ij} = x_i + b_i I_j$$

Where,

$Y_{ij}$  = observed value

$x_i$  = the estimate of  $m_i$ , and

$b_i I_j$  = Estimated value

The deviation ( $O_{ij} = Y_{ij} - b_i I_j$ ) can be squared and summed to provide an estimate of another stability parameters i.e.,  $S^2 d_i$

$$S^2 d_i = (\sum s_{ij}/(s-2) - s_e^2)/r$$

Where,

$s_e^2/r$  = estimate of pooled error, and

$$\sum s_{ij}^2 = \sum Y^2 - Y^2/t - (\sum Y^2)/\sum I_j^2$$

The Eberhart and Russell (1966) model enables partitioning the genotype x environment interaction (GE) of each genotype into two parts: (1) the variation due to the response of genotype to varying environmental indices (sum of square due to regression), and (ii) the unexplainable deviations from the regression on the environmental index.

Test of significant for individual deviation and b values was carried out as:

(a) Deviation from linear regression was tested as  $F = [\sum s_{ij}^2/(s-2)]/\text{pooled error}$

(b) The deviation of  $b_i$  value from unity was tested using the 't' test:

$$T = (b_i - 1)/SE(b) \text{ at } v(n-2) \text{ d.f.}$$

Where,

$$SE(b) = \text{pooled deviation } MS^{1/2} / \sum I_j^2$$

The test of significance of differences among the mean performance of genotypes was calculated using the 'F' test:

$$F = MS_1/MS_4$$

The test of significance of differences among genotypes in respect of mean was calculated using the 't' test:

$$t = (\mu_i - \mu) / SE(x)$$

where,

$$SE(x) = \text{pooled deviation } MS^{1/2} / (\text{number of environment} - 1)$$

$\mu_i$  = mean performance of  $i^{\text{th}}$  genotype over all the environments, and

$\mu$  = grand mean

Analysis of variance for estimation of stability parameters is as follows:

Source of variation	d.f.	S.S.	M.S.
Total	nv-1	$\sum \sum Y_{ij}^2 - CF = TSS$	
Genotype (G)	v-1	$1/n \sum Y_i^2 - CF = GSS$	$MS_1$
Environment (E)	n-1	$1/v \sum Y_j^2 - CF = ESS$	
G x E	(n-1)(v-1)	$TSS - (GSS + ESS)$	$MS_2$
E + (G x E)	v(n-1)	$\sum \sum Y_{ij}^2 - 1/n \sum Y_i^2$	
E (linear)	1	$1/v (\sum Y_{ij} I_j)^2 / \sum I_j^2$	
G x E (linear)	v-1	$\sum (\sum Y_{ij} I_j)^2 / \sum I_j^2 - E \text{ (linear)}$	$MS_3$

Pooled deviation	$v(n-2)$	$\sum \sum \sigma^2_{ij}$	$MS_4$
Genotype 1	$n-2$	$\sum Y^2_{ij} - ((1/n)(Y_i)^2 - (\sum Y_{ij}I_j)^2 / \sum I_j^2)$	
Genotype v	$n-2$	$\sum Y^2_{vj} - ((1/n)(Y_v)^2 - (\sum Y_{vj}I_j)^2 / \sum I_j^2)$	
Pooled error	$n(r-1)(v-1)$	$1/n \sum \sigma^2_{ij} = TSS - \text{Grand SS (G x E)}$	$MS_5$

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Where,

$v$  = number of genotypes

$n$  = number of environments

$\sigma^2_e$  = estimates of error mean square at each environment

Genotype x environment interaction was tested using the 'F' test:

$$F = MS_2 / MS_4$$

The genotypic differences among genotypes for their regression on the environmental index were tested using the 'F' test:

$$F = MS_3 / MS_4$$

Deviation from regression for each genotype was tested using the 'F' test:

$$F = 1/(n-2) \sum \sigma^2_{ij} / MS_5$$

## Perkins and Jink's Model (1968a)

Perkins and Jinks (1968a) proposed that the regression of genotype x environment interaction on environmental index should be obtained rather than regression of mean performance ( $Y_{ij}$ ) as given by Eberhart and Russell (1966). They describe  $Y_{ij}$  of  $i^{\text{th}}$  variety in  $j^{\text{th}}$  environment as:

$$Y_{ij} = m + d_i + e_j + g_{ij} + e_{ij}$$

Where,

$m$  = general mean

$d_i$  = additive genetic effect

$e_j$  = additive environmental effect

$g_{ij}$  = genotype x environmental effect

$e_{ij}$  = error of each observation

The stability parameters in respect of mean performance and squared deviation from regression are the same as calculated in Eberhart and Russell's model. In comparison to Eberhart and Russell's model, the regression coefficient in this model is different and is calculated from the regression of genotype x environmental interaction value on environmental index. In terms of this model, the model of Eberhart and Russell is, thus, regression of  $(e_j + g_{ij})$  on  $e_j$ . The regression of  $e_j$  on  $e_j$

being one and regression of  $g_{ij}$  on  $e_j$  being  $b_i$ , the  $b^E$  value of Eberhart and Russell model is thus:

$$b^E = 1 + b_i$$

$$b_i = b^E - 1 \text{ for each variety}$$

$$SS \text{ Genotypes} = (\sum Y_{i.}^2 / s) - (Y_{..}^2 / st)$$

$$SS \text{ Environments (Joint regression)} = (\sum I_{.j}^2 / t) - (Y_{..}^2 / st)$$

$$SS \text{ G} \times \text{E} = \sum \sum Y_{ij}^2 - (1/s)(\sum Y_{i.}^2) - (1/t)(\sum Y_{.j}^2) + (1/st)(Y_{..}^2)$$

$$SS \text{ due to heterogeneity} = \sum [\sum Y_{ij} (Y_{.j} / t) - (Y_{..} / st)^2] / \sum I_{.j}^2 - SS \text{ E}$$

$$SS \text{ remainder} = SS \text{ G} \times \text{E} - SS \text{ due to heterogeneity}$$

### Freeman and Perkins Model (1971)

Suppose that the observations come from a set of  $t$  genotypes in  $s$  environments. To use the notations of Perkins and Jinks (1968b), there are  $r$  replications of each genotype in each environment. Then, by a slight extension of Perkins and Jinks' notation, we may suppose the performance of the  $k^{\text{th}}$  replicate of the  $i^{\text{th}}$  genotype in the  $j^{\text{th}}$  environment to be given by  $y_{ijk}$ , where

$$Y_{ijk} = \mu + d_i + e_j + g_{ij} + e_{ijk}$$

Here

$\mu$  = grand mean over all replicates, genotypes and environment

$d_i$  = additive genetic contribution of the  $i^{\text{th}}$  genotype ( $i = 1 \dots, t$ )

$e_j$  = Additive environmental contribution of the  $j^{\text{th}}$  environment ( $j = 1 \dots, s$ )

$g_{ij}$  = genotype x environment interaction of the  $i^{\text{th}}$  genotype in the  $j^{\text{th}}$  environment

$e_{ijk}$  = residual variation contributed by the  $k^{\text{th}}$  replicate ( $k = 1, \dots, r$ ) of the  $i^{\text{th}}$  genotype in the  $j^{\text{th}}$  environment.

The sums of squares and degrees of freedom in the analysis of variance for variation between genotypes (G), between environments (E), genotype x environment interaction (G x E) and residual error are most conveniently represented in the following Table:

Source of variation	d.f.	Sum of squares
G	$t - 1$	$\sum Y_{i..}^2 / rs - Y_{...}^2 / rst$
E	$s - 1$	$\sum Y_{.j.}^2 / rt - Y_{...}^2 / rst$
G x E	$(t-1)(s-1)$	$\sum \sum Y_{ij.}^2 / r - \sum Y_{i..}^2 / rs - \sum Y_{.j.}^2 / rt + Y_{...}^2 / rst$
Error	$st(r - 1)$	$\sum \sum \sum Y_{ijk}^2 - \sum \sum Y_{ij.}^2 / r$

The usual least square procedure requires the minimization of the residual sum of squares  $S$ , where  $S = \sum \sum \sum (Y_{ijk} - Y_{ij})^2$ , with  $st(r-1)$  degrees of freedom.

Partitioning of analysis of variance to take into account of regression effects is as follows:

Source of variation	d.f.	Sum of squares
Genotype (G)	$t - 1$	$\sum Y_{i..}^2 / rs - Y_{...}^2 / rst$
Environment (E)	$s - 1$	$\sum Y_{.j.}^2 / rt - Y_{...}^2 / rst$
Combined regression	1	$(\sum Y_{.j.} z_j^2)^2 / rt \sum z_j^2$
Residual	$s - 2$	$\sum Y_{.j.}^2 / rt - Y_{...}^2 / rst - (\sum Y_{.j.} z_j^2)^2 / rt \sum z_j^2$
G x E Interaction	$(t-1)(s-1)$	$\sum \sum Y_{ij.}^2 / r - \sum Y_{i..}^2 / rs - \sum Y_{.j.}^2 / rt + Y_{...}^2 / rst$
Heterogeneity of regression	$(t-1)$	$[\sum (\sum Y_{ij.} z_j)^2 / r - (\sum Y_{.j.} z_j^2)^2 / rt] \sum z_j^2$
Residual	$(t-1)(s-2)$	$\sum \sum Y_{ij.}^2 / r - \sum Y_{i..}^2 / rs - \sum Y_{.j.}^2 / rt + Y_{...}^2 / rst - [\sum (\sum Y_{ij.} z_j)^2 / r - (\sum Y_{.j.} z_j^2)^2 / rt] \sum z_j^2$
Error between replicates	$st(r-1)$	$\sum \sum \sum Y_{ijk}^2 - \sum \sum Y_{ij.}^2 / r$

In order to measure various statistics, let  $X_{ij}$  denote the mean value of  $i^{\text{th}}$  genotype in the  $j^{\text{th}}$  environment ( $i=1, 2, \dots, p, j=1, 2, \dots, q$ ). Let  $X_i = \sum X_{ij}/q$ ;  $X_j = \sum X_{ij}/p$ ;  $X_{..} = \sum \sum X_{ij}/(pq)$  represent, respectively means of  $i^{\text{th}}$  genotype,  $j^{\text{th}}$  environment and overall mean. The statistics are briefly described as follows:

1. **Wricke's (1962) ecovalence ( $W^2_i$ ):** GE interaction effect for genotype  $i$ , squared and summed across all environments is the stability measure for genotype  $i$ .
2. **Shukla's (1972) stability variance ( $\sigma^2_i$ ):** Based on residuals in a two-way classification, the variance of a genotype across environments is the stability measure.
3. **Finlay and Wilkinson's (1963) regression coefficients ( $b_i$ ):** The observed values are regressed on environmental indices defined as the difference between the marginal mean of the environments and the overall means. The regression coefficient of each genotype is taken as its stability parameter.
4. **Perkins and Jinks (1968a) regression coefficient ( $\beta_i$ ):** Similar to Finlay and Wilkinson except that the observed values are adjusted for environment effects for computing regression coefficients ( $\beta_i = b_i - 1$ ).
5. **Eberhart and Russell's (1966) deviation parameter ( $S^2 d_i$ ):** The residual mean square (MS) of deviation from regression.
6. **Tai's  $\alpha_i$  and  $\lambda_i$ :** These can be regarded as a special form of  $b_i$  and  $S^2 d_i$  when environmental index is assumed to be random.

7. **Hanson (1970)'  $D_i^2$**  : Hanson (1970) proposed a stability statistic which is founded on the regression approach. This measure was termed as genotypic stability ( $D_i^2$ ) because it includes that part of the variance of environmental effects which could be reduced by breeding and selection.

These statistics are based either on the deviation from average genotype effect ( $DG = X_{ij} - X_{i.}$ ) or on the GE interaction ( $GE = X_{ij} - X_{i.} - X_{.j} + X_{..}$ ) and can be calculated with the following equations:

$W_i^2 = \Sigma(X_{ij} - X_{i.} - X_{.j} + X_{..})^2$
$\sigma_i^2 = p \Sigma(X_{ij} - X_{i.} - X_{.j} + X_{..})^2 / [(p-2)(q-1)] - SS(GE) / [(p-1)(p-2)(q-1)]$
$b_i = \Sigma(X_{ij} - X_{i.})(X_{.j} - X_{..}) / \Sigma(X_{.j} - X_{..})^2$
$\beta_i = \Sigma(X_{ij} - X_{i.} - X_{.j} + X_{..})(X_{.j} - X_{..}) / \Sigma(X_{.j} - X_{..})^2$
$\delta_i^2 = [\Sigma(X_{ij} - X_{i.})^2 - \beta_i^2 \Sigma(X_{.j} - X_{..})^2] / (q-2)$
$\delta_i^2 = [\Sigma(X_{ij} - X_{i.} - X_{.j} + X_{..})^2 - \beta_i^2 \Sigma(X_{.j} - X_{..})^2] / (q-2)$
$D_i^2 = \Sigma(X_{ij} - X_{i.} - b_{min}X_{.j} + b_{min}X_{..})^2$

In order to demonstrate interrelationships among various stability parameters, correlation coefficients were calculated between all possible pairs of stability parameters. The correlation coefficient is a measure of the degree of closeness of the linear relationship between two variables i.e., the ordinary correlation coefficient,  $r$ ,

between the values  $X_1$  and  $X_2$ . It can be calculated in the usual manner as  $\sum(x_1x_2)/\sqrt{(\sum x_1^2)} \sqrt{(\sum x_2^2)}$ .

## Chapter 4

# EXPERIMENTAL FINDINGS

## EXERIMENTAL FINDINGS

The observations recorded from the present investigations for stability of genotypes for ten characters namely, days to 50% heading, days to maturity, length of reproductive phase, plant height, number of productive tillers per plant, panicle length, number of seeds per panicle, 100-seed weight, harvest index, and grain yield per plant were subjected to the following biometrical analyses and accordingly the results are described in the following heads:

1. Effect of environments
2. Analysis of variance
3. Stability analysis
4. Relationships between different stability parameters

### 1. Effect of Environments

Large differences were observed for all the ten characters in the six environments. The mean grain yield for environments ranged from 3.24 g per plant in the environment created through late sowing and no fertilizer application to 31.61 g per plant under normal sowing with recommended dose of fertilizers (Table 1). The normal sowing and application of recommended dose of fertilizer (RDF) appeared to be favourable for expression of plant height (115.21 cm), days to 50% heading (91.31 days), number of productive tillers per plant (17.16), panicle length (11.84 cm),

number of seeds per panicle (59.18) and grain yield per plant (31.61 g) whereas delayed sowing without fertilizer resulted in lower plant height (69.44 cm), early heading (63.17 days), fewer tillers (2.98 per plant), small length of panicle (8.58 cm), early maturity (99.37 days), fewer seeds per panicle (34.99), lower harvest index (37.29%), and lower grain yield (3.24 g per plant). There was drastic reduction in the mean grain yield of genotypes when sowing was delayed and recommended dose of fertilizer was not applied.

The average plant height of the test genotypes varied from 69.44 cm in the environment created by late sowing with no fertilizer application to 115.21 cm in the environment created by normal sowing with application of recommended dose of fertilizer. There was drastic reduction in plant height from 98.30 cm under normal sown condition to 72.28 cm under late sown condition. Similarly, plant height was reduced drastically from 95.50 cm to 71.19 cm when fertilizer was not applied.

On an average, days to 50% heading ranged from 63.17 in late sown with no fertilizer environment to 91.31 in normal sown with recommended dose of fertilizer environment. Delayed sowing did not affect days to 50% heading as much as the dose of fertilizer did. For example, the test genotypes flowered earlier in 69.62 days under no fertilizer environment than 88.85 days under RDF environment whereas there was no significant difference in days to 50% heading under late (77.63) and normal (78.34) sown conditions.

Length of reproductive phase varied from 29.82 days under late sown with RDF environment to 50.49 days under normal sown with no fertilizer environment.

While normal sowing significantly increased the length of reproductive phase from 32.28 to 44.06 days, application of recommended dose of fertilizer drastically reduced it from 43.35 to 31.85 days.

The average number of productive tillers differed from 2.98 per plant under late sown with no fertilizer environment to 17.16 per plant under normal sown with RDF environment. Delayed sowing and no fertilizer equally affected the number of productive tillers per plant in the test genotypes. Delay in sowing reduced the number of productive tillers per plant drastically from 11.58 to 7.08. Similarly, the number of productive tillers per plant got reduced from 13.44 to 5.69 when no fertilizer was applied to the genotypes.

The range of average panicle length was 8.58 cm under late sown with no fertilizer environment to 11.84 cm under normal sown with RDF environment. Time of sowing did not have much influence on panicle length of genotypes. The average panicle length remained 10.5 cm when the dose of RDF was reduced to half. Further reduction in fertilizer dose, however, resulted in drastic reduction in the average panicle length to 6.32 cm.

On an average, days to maturity ranged from 99.37 under late sown with no fertilizer environment to 126.26 under normal sown with no fertilizer environment. The test genotypes took more number of days to mature under normal sown condition (122.30) than under late sown condition (109.74). Similarly, the test genotypes responded to fertilizer application and matured later in 120.69 days in RDF

environment as compared to 114.56 days in 50% RDF and 112.82 days in no fertilizer conditions.

Among the six environments created, the average number of seeds per panicle was highest in normal sown with RDF environment (59.18) and lowest in late sown with no fertilizer environment (34.99). Delayed sowing and application of no fertilizer led to drastic reduction in the number of seeds per panicle from 55.49 to 40.78 and 51.77 to 42.50, respectively.

The range of harvest index was 37.29 per cent under late sown with no fertilizer environment to 43.54 per cent under late sown with 50% RDF environment. The harvest index remained unchanged under late (40.12 per cent) and normal (40.61 per cent) sown conditions. It meant that delay in sowing proportionately affected both biological and economic yields in the test genotypes. Fifty per cent reduction in the fertilizer dose did not reduce the harvest index of genotypes. However, further reduction in the fertilizer dose reduced it to 37.82 per cent.

The average 100-seed weight of the test genotypes varied from 3.44 g in the environment created by normal sowing with no fertilizer application to 4.22 g in the environment created by normal sowing with application of 50 per cent recommended dose of fertilizer. Seed weight remained almost unchanged under late (3.74 g) and normal (3.93 g) sown conditions whereas it experienced nominal reduction when fertilizer was not applied.

Time of sowing had more impact on mean grain yield than fertilizer application resulting into wide fluctuation in the mean grain yield. Average grain

yield for late sown with no fertilizer environment was much lower than for other environments. On an average, grain yield per plant was highest (31.61 g) in the normal sown with RDF environment and lowest (3.24 g) in the late sown with no fertilizer environment. Delay in sowing time reduced the grain yield by 13.92 g per plant. There was positive response in grain yield per plant with increasing dose of fertilizer application. The single plant yield increased to 16.91 g and 23.10 g with 50% and 100% RDF application from a mere 11.54 g with no fertilizer application. Normal sowing and application of recommended dose of fertilizer appeared to be more favourable for wheat production in Bundelkhand region. Timely sowing of wheat was in particular more beneficial because of longer crop duration and better expression of yield components.

On the basis of grand mean, it was observed that the grain yield was highest in the environment created through normal sowing with recommended dose of fertilizer followed by normal sowing with 50% RDF, and normal sowing with no fertilizer. Late sown crop in combination with each of the three doses of fertilizer resulted in lower yield. Late sown crop with no fertilizer resulted in very poor yield mainly because of reduction in the expression of yield attributes like plant height, days to 50% heading, number of productive tillers per plant, panicle length, number of seeds per panicle, and harvest index.

## **2. Analysis of Variance**

To test the significance of differences among treatments, analysis of variance based on mean values of different characters was carried out separately for all the six

environments created through the manipulation of sowing dates and application of fertilizer doses. Mean squares of all the traits for different environments are presented in Tables 2 through 7. The 'F' test was highly significant for the treatments for all the 10 characters at all the six environments except for panicle length in the environment created through late sowing and no fertilizer application. This indicated that there was significant variation among the genotypes included in the study for all the ten characters studied. Similarly, time of sowing and application of different doses of fertilizer were effective in creating environmental variation.

Analysis of variance for data pooled over all the six environments revealed highly significant differences among the genotypes and environments for all the characters. The interaction between genotypes and environments (GE interaction) was also found significant for all the traits. It reflected significant variability among the treatments for most of the traits under study.

### **3. Stability Analysis**

Analysis of variance for stability parameters following Eberhart and Russell model is given in Table 8. Significant differences were found among genotypes for all the traits except for length of reproductive phase and number of productive tillers per plant. Significant variations for all the traits were also recorded among all the environments. The mean squares due to genotype x environment interaction including environmental linear effects were found to be highly significant for all the traits except panicle length, number of seeds per panicle and harvest index, reflecting differential response of the genotypes at different environments. Genotypes interacted

significantly with environments for all the traits except for days to 50% heading, days to maturity, harvest index and 100-seed weight. The presence of significant GE interaction indicated that the relative rankings of genotypes were different in different environments. Further partitioning of the GE interaction into linear and non-linear (pooled deviation) components showed that both the components were significant for plant height, length of reproductive phase, number of productive tillers per plant, number of seeds per panicle and grain yield per plant while only GE (linear) for panicle length and only pooled deviation for days to 50% heading, days to maturity, harvest index and 100-seed weight.

The mean squares due to environments (linear) indicated highly significant differences between environments and their considerable influence on all the characters. The linear component of genotype x environment interaction was found significant for plant height, length of reproductive phase, number of productive tillers per plant, panicle length, number of seeds per panicle and grain yield per plant. The nonlinear component (pooled deviation) was observed significant for all the traits except panicle length. However, when linear component of GE interaction was compared with the pooled deviation, it was found significantly different only for plant height, length of reproductive phase, number of productive tillers per plant, panicle length, number of seeds per panicle and grain yield per plant, indicating differences in linear response among genotypes in different environments. For the remaining characters i.e., days to 50% heading, days to maturity, harvest index and 100-seed weight, a relatively high proportion of GE interaction was non-linear.

The pooled analysis of variance was also worked out as per the model given by Perkins and Jinks's model, Freeman and Perkins' model and AMMI analysis, and the mean square values for different sources of variation are presented in Tables 9, 10 and 11, respectively. The partitioning of variance into various components showed that a large portion of variances was attributable to environments, GE interaction and genotypes. The genotypes and environments were highly significant for all the traits. Heterogeneity between regressions was an important source of variation for plant height, length of reproductive phase, number of productive tillers per plant, panicle length, number of seeds per panicle and grain yield per plant. As per the Freeman and Perkins model, combined regression was highly significant for all the traits while residual (linear) was significant for all the traits except for number of productive tillers per plant and number of seeds per panicle.

Analysis of variance for stability as per the AMMI model suggested highly significant variation for genotypes, environments and GE interaction for all the traits. The AMMI analysis showed that the first three PC (principal components) were highly significant for all the traits. The residual GE interaction was found insignificant for days to 50% heading, panicle length and grain yield per plant. The results, therefore, satisfied the basic requirement for the study as performance of genotypes with respect to yield and other characters varied significantly in different environments and genotypes also varied significantly so far as their average performance over all the environments was concerned.

## Stability Parameters

Besides three parameters commonly used for stability i.e., performance over the environments (mean), Finley and Wilkinson's linear regression ( $b_i$ ) and Eberhart and Russell's deviation from the regression ( $S^2d_i$ ), the phenotypic stability of the genotype was also measured by Perkins and Jinks's  $B_i$ , Tai's  $\alpha_i$  and  $\lambda_i$ , Hanson's  $D_i$ , Shukla's  $\sigma^2_i$  and Wricke's  $W^2_i$  and their values are presented on Tables 12 through 21. The characteristic performance with respect to different stability parameters is being given as under:

### Plant Height

The range of plant height varied from 73.45 cm in HUW 520 to 112.18 cm in K 9545 (Table 12). Dwarf stature of plants is considered more desirable than the tall ones. For plant height, regression coefficient ranged from 0.644 for HP 2743 to 1.617 for C 306. The linear component of GE interaction was significant for 12 genotypes and nonlinear component for 24 genotypes.

Among 25 genotypes, only HD 2733 showed stable performance across the environments, the regression value being one with non-significant deviation from regression. Moreover, the plant height of this genotype was 78.43 cm which appeared to be desirable and remained stable across the environments created through manipulation in sowing time and dose of fertilizer. The remaining genotypes had significant  $S^2d_i$  value suggesting that their performance deviated significantly from the unity and was not predictable.

The genotypes with more than one regression coefficient were UP 2472, K 8027, K 9545, K 9170, C 306 and K 8962, suggesting that these genotypes responded to good environments i.e., timely sowing and recommended dose of fertilizer whereas genotypes PBW 466, NW 1076, K 9533, HP 1731, HP 2743 and PBW 473 had significantly less than one regression coefficient indicating that these genotypes are good for poor environments i.e., delayed sowing and no fertilizer. Genotypes like NW 1014, HUW 520, HD 2733, NW 1012, PBW 450, UP 2003, HD 2285, HUW 516, HP 1838, HP 1761, PBW 443, and HP 1744 had regression value equal to one with significant deviation from regression ( $S^2d_i$ ). This showed that these genotypes had average response to environmental conditions created through sowing dates and fertilizer application but their performance was not predictable.

### **Days to 50% Heading**

The range of days to 50% heading varied from 72.30 days in HUW 234 to 84.45 days in UP 2472 (Table 13). Early flowering is considered more desirable for late sown condition. Regression coefficient for days to 50% heading varied from 0.762 for UP 2472 to 1.464 for K 9533. Four genotypes namely, K 9545, HP 1761, HP 1744 and HP 1731 showed regression coefficient close to unity ( $b_i = 1$ ) and the deviation from regression approaching zero ( $S^2d_i = 0$ ) for days to 50% heading. This indicated their average sensitivity to environmental fluctuation for time taken for heading i.e., these genotypes had linear respond to environmental conditions and their performance over environments was predictable. Among them, HP 1744 showed significantly earlier flowering than the mean.

K 9533 had significantly more than one regression value ( $b_i > 1$ ) and significant deviation from regression ( $S^2d_i = 23.581^{**}$ ) suggesting that this genotype tended to delay flowering in favourable environment that is normal sowing and application of recommended dose of fertilizer but its performance was not predictable. The remaining genotypes namely, UP 2472, NW 1014, PBW 466, HUW 520, K 8027, HD 2733, NW 1012, PBW 450, UP 2003, HD 2285, NW 1076, HUW 516, HP 1838, K 9170, PBW 443, C 306, K 8962, HUW 234, HP 2743, and PBW 473 had unit regression ( $b_i = 1$ ) and significant deviation from regression ( $S^2d_i^{**}$ ) suggesting unpredictable average response of these genotypes for environmental conditions.

### **Length of Reproductive Phase**

The length of reproductive phase varied from 32.6 days in UP 2472 to 45.84 days in HUW 234 (Table 14). Longer reproductive phase is desirable for higher productivity. The range of regression coefficient among genotypes for length of reproductive phase was 0.151 for UP 2472 to 1.668 for K 9533. Among 25 genotypes evaluated, one genotype, C 306 showed regression coefficient close to unity and the deviation from regression approaching zero for length of reproductive phase. This means that both linear as well as nonlinear components of GE interaction were non-significant for this genotype. This indicated its average sensitivity to environmental fluctuation for the length of reproductive phase. Moreover, its performance over the environments was predictable.

Genotype K 9533 showed non-significant deviation from regression with  $b_i$  more than one indicating that this genotype tended to complete its reproductive phase early in late sown and no fertilizer condition. The remaining genotypes showed significant deviation from regression and consequently were unstable in their performance. Genotypes, HUW 520, K 8027, K 8962 and HP 1731 had more than one regression coefficient with significant deviation from regression suggesting that these genotypes responded to favourable environments but their performance was not predictable.

Genotypes UP 2472, PBW 466, HUW 516, K 9170 and HP 2743 showed less than one regression coefficient and significant deviation from regression, indicating that these genotypes were adapted to poor environments but their performance was not predictable under these situations. Genotypes NW 1014, HD 2733, NW 1012, PBW450, UP 2003, HD 2285, NW 1076, HP 1838, K 9545, HP 1761, PBW 443, HP 1744, HUW 234 and PBW 473 had unit regression coefficient and significant deviation from regression suggesting that these genotypes had average response to environmental conditions, however, their performance was not predictable.

### **Number of Productive Tillers per Plant**

The range of productive tillers per plant varied from 7.49 in HP 1744 to 10.74 in K 9170 (Table 15). Effective tillers per plant provide the base for higher yield in wheat. All the genotypes had significant deviation from regression suggesting that performance of all the genotypes was not predictable and their performance appeared to be unstable with regard to number of productive tillers per plant. Regression

coefficients among different genotypes ranged from 0.609 for HP 1744 to 1.691 for K 8027 for number of productive tillers per plant.

Regression coefficient was found significant in case of number of productive tillers per plant for 10 genotypes namely, K 8027, HD 2733, HD 2285, HUW 516, HP 1838, K9170, K9533, HP 1744, K 8962, and HP 1731. Out of these ten genotypes, K 8027, HD 2733, HUW 516 and K 9170 showed more than one regression coefficient whereas the remaining genotypes had below unity regression coefficient. Fifteen genotypes had unit regression with significant deviation from regression suggesting that these genotypes had average response to environmental conditions but their performance was not predictable.

### **Panicle Length**

Length of panicle ranged from 9.07 cm in HD 2285 to 11.56 cm in K 9170 (Table 16). Regression values for panicle length varied from 0.144 for HP 1731 to 2.297 for K 8027. Genotypes UP 2472, NW 1014, PBW 466, HUW 520, HD 2733, PBW 450, UP 2003, HUW 516, HP 1838, K 9545, HP 1761, PBW 443, K 9533, C 306, HP 1744, K 8962, HUW 234, HP 2743 and PBW 473 showed unit regression and non-significant deviation from regression, suggesting that the performance of these genotypes with respect to panicle length remained stable across the environments and their performance was predictable for the created environments.

NW 1012, HD 2285 and NW 1076 had non-significant regression coefficient with significant deviation from regression. K 8027 and K 9170 had more than one regression coefficient and significant deviation from regression suggesting that these

genotypes responded well to favourable environments but their performance was not predictable. The regression value of HP 1731 differed significantly from the unity and remained below one suggesting that the genotype adapted to poor environments but its performance was unpredictable.

### **Days to Maturity**

In case of maturity, the genotypic mean over the environments varied from 113.14 days in NW 1014 to 119.10 days in K 8027 (Table 17). The range of regression coefficients for days to maturity varied from 0.816 for K 9545 to 1.262 for K 8027. All the genotypes except NW 1012 had significant deviation from regression indicating that the performance of all other genotypes was not predictable over the environments. Similarly, the regression value for all the genotypes did not differ significantly from unity thus indicating stable performance over the environments. Genotype NW 1012 had unit regression and non-significant deviation from regression indicating phenotypic stability for days to maturity with predictable performance.

### **Number of Seeds per Panicle**

Number of seeds per panicle varied from 38.96 in HP 2743 to 59.72 in HP 1731 (Table 18). Regression coefficient for number of seeds per panicle ranged from 0.211 for HUW516 to 1.922 for HP 1838. All the genotypes showed significant value of deviation from regression for number of seeds per panicle indicating that the performance of seeds per panicle was unpredictable for all the genotypes. Regression value was significantly more than one for HP 1838, K 9545, HP 1731, and PBW 473 with regard to number of seeds per panicle, suggesting that these genotypes were

adapted to good environmental conditions whereas regression value for PBW 466, HD 2733, HUW 516 and K 9170 was less than one indicating that these genotypes were adapted to poor environments but their performance was not predictable. Genotypes UP 2472, NW 1014, HUW 520, K8027, NW 1012, PBW 450, UP 2003, HD 2285, NW 1076, HP 1761, PBW 443, K 9533, C 306, HP 1744, K 8962, HUW 234, and HP 2743 had unit regression value indicating that these genotypes had average response to environmental conditions.

### **Harvest Index**

The range of harvest index varied from 30.75 per cent in UP 2472 to 47.99 per cent in HP 1744. Regression coefficients among genotypes for harvest index ranged from -1.029 for HD 2733 to 4.013 for UP 2003 (Table 19). All genotypes except UP 2003 and HP 1744 had average response to environmental conditions as their regression value did not differ from unity. All genotypes except HP 1731 showed highly significant deviation from regression suggesting their unpredictable performance in the environments created through the time of sowing and dose of fertilizer. One genotype, HP 1731, had unit regression and non-significant deviation from regression suggesting that this genotype was stable for harvest index and its performance was predictable across the environments. Genotypes UP 2003 and HP 1744 had more than one regression coefficient suggesting these genotypes were adapted to good environmental conditions. However, their performance was unpredictable as suggested by significant values of deviation from regression.

### 100-seed Weight

The range for 100-seed weight varied from 3.188 g in HUW 520 to 4.591g in C 306 (Table 20). All the genotypes showed highly significant deviation from regression suggesting their performance was not predictable across the environments. Regression coefficient for 100-seed weight ranged from 0.243 for HP 1731 to 1.985 for C 306. The  $b_i$  values were significantly more than one in only two genotypes C 306 and HP 2743 suggesting their adaptation for good environmental conditions i.e., normal sown with RDF application. However, their performance was unpredictable as indicated by significant deviation from regression parameter.

All other genotypes i.e., UP 2472, NW 1014, PBW 466, HUW 520, K 8027, HD 2733, NW 1012, PBW 450, UP 2003, HD 2285, NW 1076, HUW 516, HP 516, HP 1838, K 9545, HP 1761, K 9170, PBW 443, K 9533, HP 1744, K 8962, HUW 234, HP 1731 and PBW 473 had regression values closer to unity with significant deviation from regression for 100-seed weight, indicating their stable performance for this trait across the environments but their performance was unpredictable as indicated by the significant deviation from the regression.

### Grain Yield per Plant

The range of grain yield per plant varied from 11.59 g in HUW 520 to 30.64 g in HUW 234. The absence of GE interaction was indicated by the non-significant linear and nonlinear components for five genotypes. A simultaneous evaluation of the stability parameters ( $b_i$  and  $S^2d_i$ ) and mean for seed yield showed that five genotypes, PBW 466, HD 2733, PBW 450, HUW 516 and K 9170 had stable performance as

evident from their unit regression and a non-significant deviation from the regression (Table 21). Out of these genotypes, HD 2733, PBW 450 and K 9170 were the average yielder. This indicated the possibility of identifying genotypes giving relatively high yield in different environments. PBW 466 and HUW 516 were stable but undesirable due to low yield.

UP 2472, NW 1012, UP 2003, HD 2285, NW 1076, HP 1838, HP 1761, PBW 443, C 306, K 8962, HUW 234 and HP 2743 showed average sensitivity to variation in the environments ( $b_i = 1$ ) but their deviation from regression was high, indicating that such genotypes were unpredictable in their performance. Similarly, NW 1014, K 8027, and PBW 473 were responsive to better growing conditions ( $b_i > 1$ ) but their performance was not stable. HUW 520, HP 1744 and HP 1731 had regression value less than 1 with non-significant deviation from regression, suggesting that these genotypes were well adapted to poor growing conditions but their performance was predictable. K 9545 was not only high yielder but also a genotype which responded to good environmental conditions ( $b_i > 1$ ) with predictable performance ( $S^2d_i = 0$ ). Both  $b_i$  and  $s^2d_i$  were significant for NW 1014, K 8027, K 9533 and PBW 473 indicating that linear regression did not account for the total GE interaction.

#### 4. Relationship between Different Stability Parameters

Correlation coefficients between different stability parameters for different traits are given in Tables 22 through 31. Depending on the magnitude of correlation coefficients, the stability parameters were divided into two groups. The first group consists of  $b_i$ ,  $B_i$  and  $\alpha_i$  and the second group consists of  $S^2d_i$ ,  $W^2_i$ ,  $\sigma^2_i$  and  $\lambda_i$ .

Parameters belonging to the same group were nearly perfectly correlated, whereas all correlations between parameters belonging to different groups were small and inconsistent.  $D_i$  parameter showed its association with other stability parameters of both the groups depending on the value of  $b_i$ . None of the stability parameters was consistently associated with mean of all the traits.

### Plant Height

Table 22 showed that mean of plant height had strong positive correlation with  $b_i$ ,  $B_i$ ,  $\alpha_i$ ,  $D_i$ ,  $\sigma^2_i$  and  $W^2_i$ . There was positive and perfect correlations among  $b_i$ ,  $B_i$  and  $\alpha_i$  whereas there was positive and significant correlations among  $S^2d_i$ ,  $\lambda_i$ ,  $\sigma^2_i$  and  $W^2_i$ . Eberhart and Russell's  $b_i$ , Perkins and Jinks'  $B_i$  and Tai's  $\alpha_i$  also had positive and significant correlations with  $D_i$ ,  $\sigma^2_i$  and  $W^2_i$ . Hanson's  $D_i$  reported to have positive and significant correlation with  $\sigma^2_i$  and  $W^2_i$ .

### Days to 50% Heading

Correlation coefficients among different stability parameters and mean for days to 50% heading is given in Table 23. Average number of days to 50% heading showed positive and significant correlation with  $S^2d_i$ ,  $\lambda_i$ ,  $D_i$ ,  $\sigma^2_i$  and  $W^2_i$ . The first group consisting of regression coefficient ( $b_i$ ),  $B_i$  and  $\alpha_i$  had positive and perfect correlation among themselves and significantly positive correlation with  $D_i$  whereas correlations among deviation from regression ( $s^2d_i$ ),  $\lambda_i$ ,  $D_i$ ,  $\sigma^2_i$  and  $W^2_i$  were positive and significant.

### Length of Reproductive Phase

Table 24 depicted correlation values for different stability parameters with respect to length of reproductive phase. Mean length of reproductive phase in wheat showed positive correlation with  $S^2d_i$  and  $\lambda_i$ . There were positive and perfect correlations among regression coefficient ( $b_i$ ),  $B_i$  and  $\alpha_i$ . Similarly, Eberhart and Russell's  $S^2d_i$  had positive and significant correlation with Tai's  $\lambda_i$ ,  $\sigma^2_i$  and  $W^2_i$  which, in turn, had positive correlations among themselves. Hanson's  $D_i$  showed positive and significant correlation with  $b_i$ ,  $B_i$ , and  $\alpha_i$ .

### Number of Productive Tillers per Plant

Mean value for number of productive tillers per plant showed positive and significant correlations with  $b_i$ ,  $B_i$ ,  $\alpha_i$  and negative but significant correlation with  $\lambda_i$  (Table 25). All combinations among different stability parameters had highly significant positive correlations except the ones involving Tai's  $\lambda_i$  as one of the parameters. In these cases, the correlation values were significantly negative.

### Panicle Length

Mean value of panicle length exhibited positive and significant correlation with ( $b_i$ ),  $B_i$  and  $\alpha_i$  (Table 26). There were perfectly positive correlations among Finlay and Wilkinson's  $b_i$ , Perkins and Jinks'  $B_i$ , and Tai's  $\alpha_i$ . Correlation coefficient was positive but significant among Eberhart and Russell's  $S^2d_i$ , Tai's  $\lambda_i$ , Shukla's  $\sigma^2_i$  and Wricke's  $W^2_i$ . Hanson's  $D_i$  had significantly positive correlation with all the stability parameters except Tai's  $\lambda_i$ .

### Days to Maturity

Correlation coefficients among different stability parameters for days to maturity are presented in Table 27. The result showed that none of the stability parameters was consistently associated with mean of the days to maturity. Depending on the magnitude of correlation coefficients, the stability parameters were divided into two groups. The first group consisted of  $S^2d_i$ ,  $W^2_i$ ,  $D_i$ ,  $\sigma^2_i$  and  $\lambda_i$ , and the second group consisted of  $b_i$ ,  $B_i$  and  $\alpha_i$ . Parameters belonging to the same group were nearly perfectly correlated, whereas all correlations between parameters belonging to different groups were small and inconsistent.

### Number of Seeds per Panicle

Correlation coefficients among different stability parameters for number of seeds per panicle are presented in Table 28. Mean seeds per panicle showed significant positive correlation with  $b_i$ ,  $B_i$ ,  $\alpha_i$ ,  $S^2d_i$ , and  $D_i$ . There was significant and positive correlations among  $b_i$ ,  $B_i$ ,  $\alpha_i$ , and  $D_i$ . The correlation coefficients of  $\lambda_i$  with  $b_i$ ,  $B_i$  and  $\alpha_i$  were significant but negative. Similarly, there was significant and positive correlations among  $S^2d_i$ ,  $W^2_i$ ,  $\sigma^2_i$  and  $\lambda_i$ ,

### Harvest Index

Mean of harvest index showed positive and significant correlation with  $S^2d_i$ ,  $W^2_i$ ,  $D_i$ ,  $\sigma^2_i$  and  $\lambda_i$  (Table 29). There were significant, positive and perfect correlations among  $b_i$ ,  $B_i$  and  $\alpha_i$ . Similarly,  $S^2d_i$ ,  $W^2_i$ ,  $\sigma^2_i$  and  $\lambda_i$  had significant but positive correlations

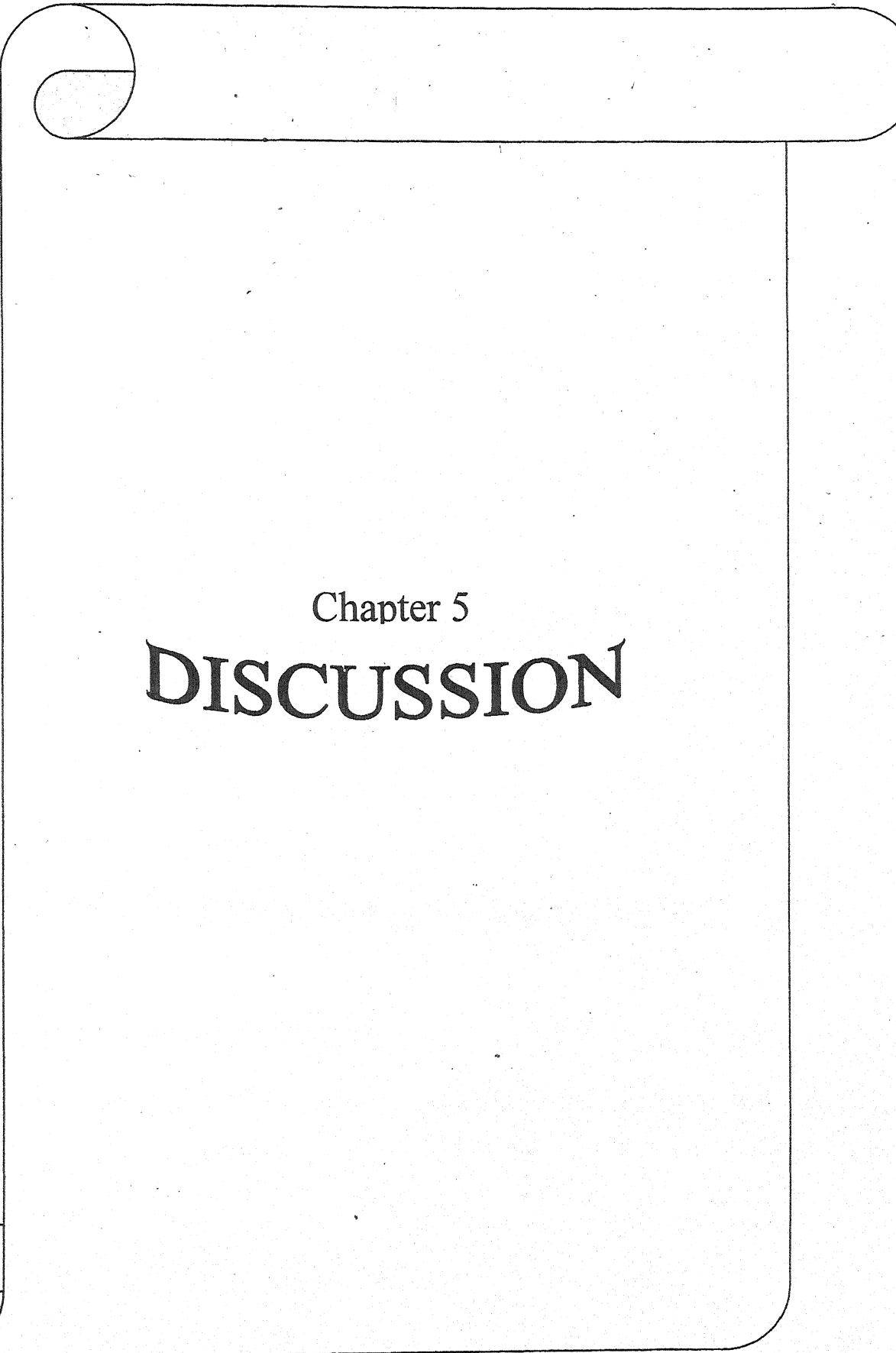
among them. Hanson's  $D_i$  had significantly positive correlations with all the stability parameters used in the present investigation.

### 100-Seed Weight

Table 30 presented correlation coefficients among different stability parameters for 100-seed weight. Mean weight of 100 seeds exhibited significant positive correlation with  $b_i$ ,  $B_i$ ,  $\alpha_i$  and  $\lambda_i$ . All pair-wise combinations of different stability parameters studied had significant and positive correlations except for  $b_i$  and  $S^2d_i$ ,  $b_i$  and  $\lambda_i$ ,  $S^2d_i$  and  $B_i$ ,  $S^2d_i$  and  $\alpha_i$ ,  $B_i$  and  $\lambda_i$ ,  $\alpha_i$  and  $\lambda_i$ , and  $\lambda_i$  and  $D_i$ .

### Grain Yield per Plant

Mean grain yield showed significant and positive correlation with all the stability parameters (Table 31). Depending on the magnitude of correlation coefficients, the stability parameters were divided into two groups. The first group consisted of  $S^2d_i$ ,  $W^2_i$ ,  $\sigma^2_i$  and  $\lambda_i$ , and the second group consisted of  $b_i$ ,  $B_i$  and  $\alpha_i$ . Parameters belonging to the same group were nearly perfectly correlated, whereas all correlations between parameters belonging to different groups were small and inconsistent. Hanson's  $D_i$  parameter showed its association with all other stability parameters of both the groups except Tai's  $\lambda_i$ .

A decorative border consisting of a thin black line. It features a horizontal bar at the top with a scroll-like end on the left. The main body is a large rectangle with rounded corners. At the bottom left, there is a large, stylized scroll-like element that curves upwards and to the right.

Chapter 5

# DISCUSSION

## DISCUSSION

Wheat (*Triticum aestivum* Linn. Emend. Thell) is a unique cereal crop which has a wide range of adaptation and is successfully grown in different agro-climatic regions of the world under diverse environmental conditions such as extremities in temperature, moisture, photoperiod and soil fertility. A major breakthrough in wheat production throughout the world is brought about by the introduction and adoption of high yielding nitrogen responsive genotypes possessing dwarfing genes. These genotypes have exhibited remarkable range of plasticity. Even high yielding cultivars with common ancestry have different degrees of adaptation. The basic aim of wheat breeding programme is, therefore, to evolve varieties with high yield potential and wide adaptation over varied environmental conditions. The present investigation was an effort in this direction to assess the amount and nature of genotype x environment interaction, to determine the stability parameters for adaptation of newly developed genotypes, to identify high yielding and stable genotypes for Bundelkhand region and to assess different stability parameters for their effectiveness in measuring the GE interaction

Yield is the end product of interaction among a large number of quantitative traits each of which is generally controlled by many genes with small effect. The characters having more number of loci for their expression exhibit considerable influence of environmental fluctuations and GE interaction. The inherent yielding ability of wheat is generally expressed through plant type and yield attributes like length of panicle, seed weight, productive tillers, harvest index, etc., and, therefore,

selection of superior genotypes is generally based on phenotypic expression of these traits. Often the selection based on the phenotypic expression does not lead to the expected genetic advance mainly due to the influence of genotype x environment interactions as well as due to undesirable associations existed between different yield contributing characters at genotypic level.

The knowledge of genotype x environment interaction is of major significance to plant breeders for developing improved varieties with wide adaptability. The smaller the GE interaction variance, the more is the consistent performance for a particular genotype over a wide array of agro-climatic conditions. Since stability is an inherent ability of a cultivar having minimum interaction with the environment, preliminary evaluation can be made to identify the stable genotypes in early generations. However, selection for stability is possible only when a model with suitable parameters is applied to rank the genotypes for stability. A variety that has an above average performance in all the environments is generally released for cultivation. Hence, the genotypes with high mean, unit regression coefficient and the smallest deviation from regression will be the automatic choice for selection (Eberhart and Russell 1966). According to Langer et al. (1979), the regression coefficient is a measure of response to varying environments. The mean square of deviation from linear regression is a true measure of production stability.

To detect GE interaction, at least two genotypes must be evaluated in at least two environments. GE interaction signifies nonadditivity and makes up a substantial part of phenotypic expression of quantitative traits like grain yield. The higher the GE interaction the more will be difficult to assess breeding value of an individual. Had

there been no GE interaction, a single location trial without any replication would have been sufficient to identify the best variety for a crop and that genotype would have prospered worldwide irrespective of the environmental conditions. Lack of GE interaction can also imply a lack of genetic diversity, which can be disastrous because of the associated genetic vulnerability to disease epidemics, insect infestations, or other factors. But this kind of situation does not exist in the nature.

Invariably in the multilocation yield trials, the relative differences among genotypes across environments are inconsistent due to GE interaction. These differences manifest themselves either qualitatively by altering the relative ranking of genotypes among environments, which reflects a lack of genetic correlations among environments or quantitatively by changing absolute differences between genotypes without changing ranks, which reflects heterogeneity of variance. Knowledge of the relationship between genotype and phenotype in different environments helps breeders to make accurate predictions of the response to selection in crops that are being grown in spatially or temporally heterogeneous environments. If the phenotypic expression of a genotype is dependent on growing conditions (i.e., sufficient phenotypic plasticity is present), measures of its heritability would also vary across growing conditions. If phenotypic ranks of two genotypes change across environments, the genotype favoured by selection will differ between environments. However, if ranks remain unchanged but the magnitude of phenotypic differences increases across environments, the estimates of heritability and predicted response to selection will increase whereas the genotypes favoured by selection remains unchanged.

In response to severe environmental changes, a genome can respond in a rapid and specific manner by selectively regulating the expression of specific genes. Plants have acquired a variety of environmental signals into their developmental pathways that have endowed them with wide range of adaptive capacities over time. This property of plants is termed as phenotypic plasticity. Features of phenotypic plasticity encompass modification of phenotype in a single genotype, responsiveness to changes in environment and changes having adaptive value that allow an individual to withstand environmental stress. These are the mechanisms by which plants are able to acclimatize themselves to a number of environmental stresses such as cold, heat shock, anaerobic conditions and light.

There are two ways through which a population can achieve stability i.e., individual buffering belonging to genetically homogeneous population such as inbred lines and population buffering which arises from the interaction of different coexisting genotypes (heterogeneous population). A relationship has been reported in both plants and animals between stability and degree of heterozygosity. However, there is an equal amount of evidence that stability can be determined by gene system unrelated to heterozygosity as such.

Stability analysis has been a subject of great interest among wheat breeders and often been carried out in the past [Gandhi et al. (1964), Bains and Gupta (1972), Ahmad et al. (1980), Gill et al. (1980), Jatasra and Paroda (1980), Chaubey and Sastry (1981), Nanda et al. (1983), Manake et al. (1991), Deswal et al. (1996), Bhullar et al. (1983), Mishra et al. (1990), Atale et al. (1991), Mishra et al. (1991), Kishor et al. (1992), Rajput and Ahmad (1992), Mishra and Chandraker (1992),

Bhavsar et al. (1996a), (1996b), Menon and Sharma (1996), Kara (2000), Mishra et al. (2000), Malariya et al. (2001) and Singh et al. (2002)]. However, there is hardly any study for environmental conditions represented by Bundelkhand regions where wheat is generally taken up even under very late sown conditions. In such situations, sowing time, spacing, seed rates, fertilizer application and water supply are directly helpful for harvesting a successful crop. If selection for stability is the main purpose of a breeding programme, the breeding material should be evaluated both for sensitivity to environment and relative performance. Environment should include all those factors that might be limiting under the conditions in which material will ultimately be grown. Keeping the above considerations in mind, the present study in wheat was undertaken in Bundelkhand under six environmental conditions created through manipulation in the time of sowing and dose of fertilizer application.

Observations on the environmental conditions and varietal response for each individual test suggested that the sowing time and amount of fertilizer dose were able to create different environments and were the primary factors determining the relative varietal performance. For example, early varieties tended to do well and be favoured under late sown conditions whereas late maturing varieties tended to do well under normal sown conditions. The normal sowing and application of recommended dose of fertilizer (RDF) appeared to be favourable for expression of plant height (115.21 cm), days to 50% heading (91.31 days), number of productive tillers per plant (17.16), panicle length (11.84 cm), number of seeds per panicle (59.18) and grain yield per plant (31.61 g) whereas delayed sowing without fertilizer resulted in lower plant height (69.44 cm), early heading (63.17 days), fewer tillers (2.98 per plant), small

length of panicle (8.58 cm), early maturity (99.37 days), fewer seeds per panicle (34.99), lower harvest index (37.29%), and lower grain yield (3.24 g per plant). There was drastic reduction in the mean grain yield of genotypes when sowing was delayed and recommended dose of fertilizer was not applied.

In the present study, stability parameters of 25 advanced breeding lines was computed based on the models given by Finlay and Wilkinson (1963), Eberhart and Russell (1966), Perkins and Jinks (1968a), Freeman and Perkins (1971) and several other stability parameters at six environments created through the manipulation of sowing dates and fertilizer doses at Brahmananda Mahavidyalaya, Rath, a town in Bundelkhand region of Uttar Pradesh. Different Stability parameters used in the present analysis for ranking of genotypes for different traits were found associated with each other in such a way that mean and deviation from regression is similar and the regression coefficient of Perkins and Jinks model is equivalent to  $b^E - 1$ . The  $b^E$  is regression coefficient of Finlay and Wilkinson and Eberhart and Russell models. Consequently, the ranking pattern of the genotypes under Perkins and Jinks model was similar to the pattern under Finlay and Wilkinson and Eberhart and Russell models. Finlay and Wilkinson (1963) defined a genotype with  $b_i = 0$  as stable. This definition is according to the static concept proposed by Becker (1981). Eberhart and Russell (1966), on the contrary, defined a genotype with  $b_i = 1$  to be stable. This definition is in accordance with the dynamic concept, but it would be preferable to use the ecovalence which combines  $b_i$  and  $S^2d_i$  into one parameter.

In the present study, the ranking pattern of genotypes for the responsiveness using regression values has been concluded on the basis of Eberhart and Russell

model. The present investigation pointed out that four models used have almost equal frequency for selecting the desirable genotypes under different environments. This is in general agreement with the results presented by Eberhart et al. (1974), Jalaluddin and Harrison (1990), Soni et al. (1991), Kara (1996), Ortiz et al. (2001) and Robert (2002). Besides three parameters commonly used for stability i.e., performance over the environments (mean), Finley and Wilkinson's linear regression ( $b_i$ ) and Eberhart and Russell's deviation from the regression ( $S^2d_i$ ), the phenotypic stability of the genotype was also measured by Perkins and Jinks's  $B_i$ , Tai's  $\alpha_i$  and  $\lambda_i$ , Hanson's  $D_i$ , Shukla's  $\sigma^2_i$  and Wricke's  $W^2_i$ .

The experimental results indicated that the pattern of GE interactions among genotypes was not similar with the traits under study. Pooled analysis of variance showed that the mean differences between the genotypes, environments and GE interactions were highly significant for all the characters, except genotypic variation for length of reproductive phase and number of productive tillers per plant, and GE interaction for days to 50% heading, days to maturity, harvest index and 100-seed weight which revealed that the average performance of the genotypes with regard to grain yield and other attributes varied significantly over the environments.

The large GE interaction component for yield and yield attributes observed in the present study is in conformity with previous reports of Bains and Gupta (1972), Ahmad et al. (1980), Gill et al. (1980), Jatasra and Paroda (1980), Chaubey and Sastry (1981), Nanda et al. (1983), Manake et al. (1991), Deswal et al. (1996), Bhullar et al. (1983), Mishra et al. (1990), Atale et al. (1991), Mishra et al. (1991), Kishor et al. (1992), Rajput and Ahmad (1992), Mishra and Chandraker (1992),

Bhavsar et al. (1996a), (1996b), Menon and Sharma (1996), Kara (2000), Mishra et al. (2000), Malariya et al. (2001) and Singh et al. (2002). This indicates that wheat varieties often show differential response when grown under different environmental conditions created by time of sowing and amount of fertilizer applied. Small and non-significant GE interaction for days to 50% heading, days to maturity, harvest index and 100-seed weight, however, indicated that there was no consistent environment effect on different varietal response.

The mean squares due to environments (linear) indicated highly significant differences between environments and their considerable influence on all the characters. The mean squares due to genotype x environment interaction including environmental linear effects were found to be highly significant for all the traits except panicle length, number of seeds per panicle and harvest index, reflecting differential response of the genotypes at different environments. This might be responsible for high adaptation in relation to yield attributes in wheat. Similar findings were reported by Bedo and Balla (1977), Jatasra and Paroda (1980), Nanda et al. (1983) and Kerkhi (1987).

The presence of significant GE interaction indicated that the relative rankings of genotypes were different in different environments. Further partitioning of the GE interaction into linear and non-linear (pooled deviation) components showed that the linear component of genotype x environment interaction was significant for plant height, length of reproductive phase, number of productive tillers per plant, panicle length, number of seeds per panicle and grain yield per plant. The nonlinear component (pooled deviation) was observed significant for all the traits except

panicle length. However, when linear component of GE interaction was compared with the pooled deviation, it was found significantly different only for plant height, length of reproductive phase, number of productive tillers per plant, panicle length, number of seeds per panicle and grain yield per plant, indicating differences in linear response among genotypes in different environments. For the remaining characters i.e., days to 50% heading, days to maturity, harvest index and 100-seed weight, a relatively high proportion of GE interaction was non-linear indicating that prediction of the performance of different genotypes for different environments will not be feasible. In this situation the deviation from regression ( $S^2d_i$ ) is a more important criterion for assessing the stability of genotypes.

Most of the traits showed general pattern of environmental variance being larger than the GE interaction and genotypes. This is in general agreement with previous reports (Ahmad et al. 1980; Gill et al. 1980; Nanda et al. 1983; Deswal et al. 1996; Atale et al. 1991; Mishra et al. 1991; Kishor et al. 1992; Mishra and Chandraker 1992; Menon and Sharma 1996; Mishra et al. 2000; and Singh et al. 2002) indicating that GE interaction effects greatly overshadowed varietal differences for traits in wheat. The presence of a substantial GE interaction for yield and yield traits indicates that it is essential to test wheat varieties over a number of different environments. GE interactions were significant for all characters but no genotype was stable for all characters.

The variance due to pooled deviation (non-linear) were highly significant for all the traits except panicle length reflecting considerable genetic diversity in the material. This is in line with the observations of Perkins and Jinks (1968b). Such non-

linear deviation may also be of practical value to construct and to test the utility of multiple regression models to know more critically the complex mechanism of adaptations.

Some genotypes showed highly stable performance for yield and yield attributes over environments. The significance of GE interaction (linear component) emphasized that the genotypes deviating significantly from the regression line of unit slope could be identified. Accordingly, three kinds of linear responses namely,  $b = 1$ ,  $b > 1$  and  $b < 1$  has been generally observed. However, in the present study negative  $b_i$  values were observed for harvest index. Such type of linear response could be attributed due to inadequacy of the scale used for the analysis and/or the inherent behaviour of the genotypes investigated (Knight 1970).

The large variation in regression coefficients in the present material indicated that the genotypes and their derivatives had different degrees of environmental responses. Pfahler and Linsken (1979) pointed out that to some extent variability among environments could determine the usefulness of regression response parameters. The results of phenotypic stability of 25 genotypes tested at six environments and measured for ten characters by three parameters namely, mean performance over environments, the linear regression and the deviation from regression are discussed character wise below:

### **Plant Height**

A wide range of variation was observed for plant height among the 25 genotypes. Genotype HD 2733 showed stable performance across the environments as the

regression value was approaching one with non-significant deviation from regression. Moreover, the plant height of this genotype was 78.43 cm which appeared to be desirable and remained stable across the environments created through manipulation in sowing time and dose of fertilizer. This indicates greater buffering capacity of this genotype over a wide range of environments. The remaining genotypes had significant  $S^2d_i$  value suggesting that their performance deviated significantly from the unity and their performance was not predictable.

The genotypes with regression coefficient more than one were UP 2472, K 8027, K 9545, K 9170, C 306 and K 8962, suggesting that these genotypes responded to good environments that is timely sowing and recommended dose of fertilizer whereas genotypes PBW 466, NW 1076, K 9533, HP 1731, HP 2743 and PBW 473 had significantly less than one regression coefficient indicating that these genotypes are good for poor environments that is delayed sowing and no fertilizer. This shows nonlinear response of genotypes to wide range of environmental conditions. Genotypes like NW 1014, HUW 520, HD 2733, NW 1012, PBW 450, UP 2003, HD 2285, HUW 516, HP 1838, HP 1761, PBW 443, and HP 1744 had regression value equal to one with significant deviation from regression ( $S^2d_i$ ). This showed that these genotypes exhibited average response to environmental conditions created through sowing dates and fertilizer application but their performance was not predictable.

### **Days to 50% Heading**

Four genotypes namely, K 9545, HP 1761, HP 1744 and HP 1731 showed regression coefficient close to unity ( $b_i = 1$ ) and the deviation from regression approaching zero

( $S^2d_i = 0$ ) for days to 50% heading. This indicated their average sensitivity to environmental fluctuation for time taken for heading i.e., these genotypes had linear response to environmental conditions and their performance over environments was predictable. These genotypes may be considered as stable genotypes with regards to days to 50 per cent heading. Among these, HP 1744 showed significantly earlier flowering than the mean. K 9533 had significantly more than one regression coefficient ( $b_i > 1$ ) and significant deviation from regression ( $S^2d_i = 23.581$ ) suggesting that this genotype tended to delay flowering in favourable environment that is normal sowing and application of recommended dose of fertilizer but its performance was not predictable. The remaining genotypes had unit regression ( $b_i = 1$ ) and significant deviation from regression ( $S^2d_i$ ).

### **Length of Reproductive Phase**

Among 25 genotypes evaluated, only one genotype, C 306 showed regression coefficient close to unity and the deviation from regression approaching zero for length of reproductive phase. This means that both linear as well as nonlinear components of GE interaction were non-significant for this genotype. This indicated its average sensitivity to environmental fluctuation for the length of reproductive phase. K 9533 showed non-significant deviation from regression with  $b_i$  more than one indicating that this genotype tended to complete its reproductive phase early in late sown and no fertilizer condition. The remaining genotypes showed significant deviation from regression and consequently were unstable in their performance.

Genotypes, HUW 520, K 8027, K 8962 and HP 1731 had more than one regression with significant deviation from regression suggesting that these genotypes responded to favourable environments but their performance was not predictable. Genotypes UP 2472, PBW 466, HUW 516, K 9170 and HP 2743 showed less than one regression coefficient and significant deviation from regression, indicating that these genotypes are adapted to poor environments but their performance was not predictable under these situations. Genotypes NW 1014, HD 2733, NW 1012, PBW450, UP 2003, HD 2285, NW 1076, HP 1838, K 9545, HP 1761, PBW 443, HP 1744, HUW 234 and PBW 473 had unit regression and significant deviation from regression suggesting that these genotypes did not respond to environmental conditions, however, their performance was not predictable.

#### **Number of Productive Tillers per Plant**

All the 25 genotypes had significant deviation from regression suggesting that performance of these genotypes was not predictable and their performance appeared to be unstable with regard to tillers per plant. Regression coefficient was found significant for ten genotypes namely, K 8027, HD 2733, HD 2285, HUW 516, HP 1838, K9170, K9533, HP 1744, K 8962, and HP 1731. Out of these ten genotypes, K 8027, HD 2733, HUW 516 and K 9170 showed more than one regression coefficient whereas the remaining genotypes had below unity regression. K 8027, HD 2733, HUW 516 and K 9170 may be well adapted to good environmental conditions like timely sowing and full dose of fertilizer. Fifteen genotypes had unit regression with significant deviation from regression suggesting that these genotypes showed average response to environmental conditions but their performance was not predictable.

### **Panicle Length**

Length of panicle exhibited wide range of variation. Genotypes UP 2472, NW 1014, PBW 466, HUW 520, HD 2733, PBW 450, UP 2003, HUW 516, HP 1838, K 9545, HP 1761, PBW 443, K 9533, C 306, HP 1744, K 8962, HUW 234, HP 2743 and PBW 473 showed unit regression and non-significant deviation from regression, suggesting that the performance of these genotypes with respect to panicle length remained stable across the environments and their performance was predictable under the created environments. NW 1012, HD 2285 and NW 1076 had non-significant regression value with significant deviation from regression. K 8027 and K 9170 had more than one regression coefficient and significant deviation from regression suggesting that these genotypes responded well to favourable environments but their performance was not predictable. The regression value of HP 1731 differed significantly from the unity and remained below one suggesting that the genotype adapted to poor environments but its performance was unpredictable.

### **Days to Maturity**

All the genotypes except NW 1012 had significant deviation from regression indicating that the performance of all these genotypes was not predictable over the environments. Similarly, the regression value for all the genotypes did not differ significantly from unity thus indicating stable performance over the environments. Genotype NW 1012 had unit regression and non-significant deviation from regression indicating phenotypic stability for days to maturity. Therefore, this genotype which takes about 116 days to mature with 14.75 g grain yield per plant may be grown

under a wide range of environmental conditions i.e., time of sowing and fertilizer dose.

### **Number of Seeds per Panicle**

All the genotypes showed significant value for deviation from regression for number of seeds per panicle indicating that the performance was unpredictable for all the genotypes. Regression value was significantly more than one for HP 1838, K 9545, HP 1731, and PBW 473 with regard to number of seeds per panicle, suggesting that these genotypes are adapted to good environmental conditions whereas regression value for PBW 466, HD 2733, HUW 516 and K 9170 was less than one indicating that these genotypes were adapted to poor environments but their performance was not predictable. Genotypes UP 2472, NW 1014, HUW 520, K8027, NW 1012, PBW 450, UP 2003, HD 2285, NW 1076, HP 1761, PBW 443, K 9533, C 306, HP 1744, K 8962, HUW 234, and HP 2743 had unit regression value indicating that these genotypes had average response to environmental conditions.

### **Harvest Index**

One genotype, HP 1731, had unit regression and non-significant deviation from regression suggesting that this genotype was stable for harvest index and its performance was predictable across the environments. Genotypes UP 2003 and HP 1744 had more than one regression value suggesting these genotypes are adapted to good environmental conditions.

### 100-seed Weight

All the genotypes showed highly significant deviation from regression suggesting their performance was not predictable across the environments. The  $b_i$  values were significantly more than one in only two genotypes C 306 and HP 2743 suggesting their adaptation for good environmental condition. All other genotypes had regression values closer to unity with significant deviation from regression for 100-seed weight, indicating their stable performance for this trait across the environments but their performance was predictable as indicated by the significant deviation from the regression.

### Grain Yield per Plant

For grain yield, both linear and non-linear components of GE interaction were significant and prediction of performance across the environments appeared to be difficult for the traits. Eberhart and Russell (1966) defined stable genotypes as those having unit regression coefficient ( $b_i = 1$ ) and non-significant deviation from the regression ( $S^2d_i$ ). The absence of GE interaction was indicated by the non-significant linear and nonlinear components for five genotypes. A simultaneous evaluation of the stability parameters ( $b_i$  and  $S^2d_i$ ) and mean for seed yield showed that five genotypes, PBW 466, HD 2733, PBW 450, HUW 516 and K 9170 had stable performance as evident from their unit regression and a non-significant deviation from the regression. It means that these genotypes are widely adapted under a range of planting times and doses of fertilizer. Out of these genotypes, HD 2733, PBW 450 and K 9170 were the average yielder. This indicated the possibility of identifying genotypes giving

relatively high yield in different environments. PBW 466 and HUW 516 were stable but undesirable due to low yield. These genotypes show wide adaptation and may be recommended for cultivation under normal sown with 100% RDF condition as well as under late sown and no fertilizer environment.

Genotypes UP 2472, NW 1012, UP 2003, HD 2285, NW 1076, HP 1838, HP 1761, PBW 443, C 306, K 8962, HUW 234 and HP 2743 showed average sensitivity to variation in the environments ( $b_i = 1$ ) but their deviation from regression was high, indicating that such genotypes were unpredictable in their performance. Similarly, NW 1014, K 8027, and PBW 473 were responsive to better growing conditions ( $b_i > 1$ ) but their performance was not stable. These genotypes are expected to perform well under normal sown and 100% RDF environment of Bundelkhand region.

HUW 520, HP 1744 and HP 1731 had regression value less than 1 with non-significant deviation from regression, suggesting that these genotypes were well adapted to poor growing conditions but their performance was predictable. These genotypes may be recommended for late sown condition with no fertilizer of Bundelkhand region. K 9545 was not only high yielder but also a genotype which responded to good environmental conditions ( $b_i > 1$ ) with predictable performance ( $S^2d_i = 0$ ). Both  $b_i$  and  $S^2d_i$  were significant for NW 1014, K 8027, K 9533 and PBW 473 indicating that linear regression did not account for the total GE interaction.

The present data do not preclude the possibility of selecting or breeding varieties for specific environments in those cases where the important environmental factors are under some degree of control and can thus be predicted at planting time.

For example, a grower who consistently plant his wheat crop in time and uses full dose of fertilizer may need a different variety in order to realize maximum yields than his neighbour who neither plant his crop in time nor apply any fertilizer. Chaubey and Sastry (1981), Malik and Rajpur (1984), Thete *et al.* (1987), Rasal *et al.* (1988), Maloo *et al.* (1993), Deswal *et al.* (1996), Mishra *et al.* (2000) also studied stability analysis of wheat varieties over the environments created through planting dates and fertilizer doses and found significant GE interaction. The results of the present investigations are in general agreement with the results of the above reports.

Chaubey and Sastry (1981) investigated yield and six yield components of 25 varieties grown in four environments created by the application of different combinations of NPK and irrigation. No variety was stable for all characters but most were stable for number of days to flowering and ear number per plant. The results of the present investigation also indicate that no variety was stable for all the characters. Varieties of moderate height were more stable than tall or dwarf varieties. Malik and Rajput (1984) studied stability of wheat cultivars under four fertilizer regimes (different N + P combinations). Values for all three traits were increased by fertilizer application although the fertilizer doses themselves were regarded as non-significant as have been the findings of the present study. Therefore, it is recommended that yield potential and adaptability be assessed under different environments before varietal release.

Thete *et al.* (1987) reported significant differences between environments and varieties and also for different traits when 24 varieties were evaluated on three different dates at two sites. No variety was stable for all the traits. Rasal *et al.* (1988)

evaluated 24 wheat cultivars on three sowing dates at two locations to study the effect of environmental factors. There were significant differences between environments, cultivars and also for genotype x environment interaction. Maloo *et al.* (1993) studied GE interaction for grain yield, biological yield and harvest index using 40 diverse wheat varieties/strains over nine environments created by sowing dates, fertilizer dose and irrigation levels in three successive years. GE interaction was significant for all the traits. Both linear and non-linear portions of GE interactions were significant for biological yield with predominance of linear component. Non-linear component was significant for grain yield and harvest index. The mean performance appeared to be associated with linear response and stability for grain yield. These findings are in general conformity with the present results.

Deswal *et al.* (1996) evaluated wheat cultivars for harvest index, plant height, number of tillers/30 cm, grain weight/spike and 1000-grain weight under three environments (timely sown, high fertility and irrigated; timely sown, low fertility and rainfed; and late-sown, high fertility and irrigated). Significant GE interactions were observed for plant height, number of tillers/30 cm and grain weight/spike. Both predictable and unpredictable components shared the GE interaction for plant height and number of tillers/30 cm. However, for grain weight/spike, the non-linear component was predominant. In spite of non-significant GE interactions, the linear component was significant for 1000-grain weight. Mishra *et al.* (2000) also studied eight promising wheat genotypes on three different dates (normal, 22 November; late, 2 December; and very late, 12 December). The results showed that DL 788-2 and GW 190 had higher adaptability and stability, and may be recommended for normal and

late sowing conditions. The cultivar WH 147 was responsive to rich environments and may be recommended for cultivation based on normal sowing dates. DL 803-3 and Raj 1555 showed stability and sustainability under poor environmental conditions and may be recommended for cultivation under late sowing conditions.

### Comparison among Stability Parameters

Some of the above stability parameters have been compared statistically elucidating useful theoretical interrelationships among them (Becker, 1981; Lin et al., 1986 and Kang et al., 1987). Besides theoretical relationships, empirical correlation is also useful to quantify interdependence of different stability parameters particularly between those whose mathematical models are inexplicit in showing their mutual relations. Eberhart *et al.* (1974) applied the models of Eberhart and Russell, Perkins and Jinks and Freeman and Perkins to study genotype x environment interactions. The models of Eberhart and Russell, and Perkins and Jinks produced similar results with respect to both responsiveness ( $b_i$ ) and stability ( $S^2d_i$ ). Freeman and Perkins' model produced similar results to these two models for the pattern of  $b_i$  values. The pattern of correlations between environments ( $r$ ) for various genotypes showed high similarity with the pattern of  $b_i$  values obtained with the various models and varieties with high  $b_i$  values had high environmental correlations. Ecovalence ( $W^2_i$ ) calculations and Freeman and Perkins' model gave similar results in determining the stability of a genotype. Correlations between ecovalence and Eberhart and Russell's  $S^2d_i$  were also very high. However, most stable varieties could be detected using any

of these models. The use of correlation between environments and ecovalence is suggested for predicting responsiveness and stability of genotypes, respectively.

In the present study, a very strong positive correlation was observed among  $b_i$ ,  $B_i$  and  $\alpha_i$  for all the traits. This is in agreement with the earlier reports (Becker, 1981; Lin et al., 1986 and Kang et al., 1987). All the three parameters depend mainly on the deviation from the average genotypes effect across environments. Consequently,  $b_i$ ,  $B_i$  and  $\alpha_i$  are expected to be highly correlated.

The  $b_i$  is often considered to be associated with mean. In this study also,  $b_i$ ,  $B_i$  and  $\alpha_i$  had high correlation with the mean of plant height, number of productive tillers per plant, panicle length, seeds per panicle, 100-seed weight and grain yield per plant. This indicates that a high mean yield was necessarily associated with average regression, indicating that there is limited possibility of combining high mean yield with high stability. The positive correlation between regression coefficient and mean performance also indicates that low yielding genotypes were generally stable while high yielding ones were rather responsive. It means that stability is often associated with a relatively poor response and low yield in environments that are high yielding for other cultivars. This type of correlation was also reported by Finlay and Wilkinson (1963) and others. Another reason is that although a high level of performance under a wide range of environments may be desirable, it is difficult to achieve in practice. Even if it can be achieved, the effort is not entirely necessary because several less widely adapted cultivars can be bred and then grown separately in different environments to achieve maximum production (Lin et al., 1986). Hardwick (1981) explained the above correlation and showed that the condition for the positive

correlation to occur between regressions and means is that the regressions should be concurrent and pass through a common point. This implies that in certain environments the differences in performance between genotypes must disappear.

Very strong correlation was observed between all possible pairs among  $S^2d_i$ ,  $\lambda_i$ ,  $\sigma^2_i$  and  $W^2_i$  for plant height, days to 50 per cent heading, length of reproductive phase, number of productive tillers per plant, panicle length, days to maturity, seeds per panicle, harvest index, 100-seed weight and grain yield per plant. A high correlation among them is expected when nonlinear component of GE interaction is predominant i.e., the data do not fit the linear model or the data fit the linear model but all  $b_i$ 's are equal. In this study the data do not fit the linear model and consequently, the correlation among  $S^2d_i$ ,  $\lambda_i$ ,  $\sigma^2_i$  and  $W^2_i$  was very high.  $S^2d_i$ ,  $\lambda_i$  and  $\sigma^2_i$  are linear combination of the ecovalence and, therefore, all are equivalent for ranking purpose. With careful interpretation any one of the parameters would be used to measure stability. However, Shukla's  $\sigma^2_i$  may be preferred over others as it provides a test for the homogeneity of the estimates. All these parameters were found independent with mean except for days to 50 per cent heading, harvest index and grain yield per plant. These results are in agreement with the results of Becker (1981), Heine and Weber (1982), Lin et al. (1986) and Soni et al. (1989).

# SUMMARY AND CONCLUSION

## SUMMARY AND CONCLUSION

The present investigation "**Phenotypic stability of some wheat (*Triticum aestivum* L.) genotypes under Bundelkhand conditions**" was undertaken to assess the amount and nature of genotype x environment (GE) interaction, to determine the stability parameters for adaptation of newly developed genotypes, to identify high yielding and stable genotypes for Bundelkhand region and to assess different stability parameters for their effectiveness in measuring the GE interaction.

During Rabi 2001-02, 25 genotypes were sown in a Randomized Complete Block Design with three replications under artificially created six environments at Rath. The environments were created by sowing genotypes under normal and late conditions with three regimes of fertilizers *i.e.*, recommended dose of fertilizer, 50% of the recommended dose of fertilizer and without fertilizer application. Each genotype was sown in six-row plot by dibbling method under each environment. Observations were recorded for days to 50% heading, days to maturity, length of reproductive phase, plant height, number of productive tillers per plant, panicle length, number of seeds per spike, 100-seed weight, harvest index and grain yield per plant.

Observations on the environmental conditions and varietal response for each individual test suggested that the sowing time and amount of fertilizer dose were able to create different environments and were the primary factors determining the relative varietal performance. The mean grain yield for environments ranged from 3.24 g per

plant in the environment created through late sowing and no fertilizer application to 31.61 g per plant under normal sowing with recommended dose of fertilizers. The normal sowing and application of recommended dose of fertilizer (RDF) appeared to be favourable for expression of plant height (115.21 cm), days to 50% heading (91.31 days), number of productive tillers per plant (17.16), panicle length (11.84 cm), number of seeds per panicle (59.18) and grain yield per plant (31.61 g) whereas delayed sowing without fertilizer resulted in lower plant height (69.44 cm), early heading (63.17 days), fewer tillers (2.98 per plant), small length of panicle (8.58 cm), early maturity (99.37 days), fewer seeds per panicle (34.99), lower harvest index (37.29%), and lower grain yield (3.24 g per plant). There was drastic reduction in the mean grain yield of genotypes when sowing was delayed and recommended dose of fertilizer was not applied.

The experimental data were compiled by taking mean of each treatment for all the replications for each environment, then pooled and were then subjected to the statistical and biometrical procedures following Finlay and Wilkinson model (1963), Eberhart and Russell model (1966), Perkins and Jinks model (1968b) and Freeman and Perkins model (1971) besides other stability parameters being commonly used for stability analysis.

Analysis of variance indicated highly significant differences among the treatments for all the 10 characters at all the six environments except for panicle length in the environment created through late sowing and no fertilizer application. Analysis of variance for data pooled over all the six environments revealed highly significant differences among the genotypes and environments for all the characters.

The interaction between genotypes and environments was also found significant for all the traits.

Analysis of variance for stability parameters following Eberhart and Russell model showed significant differences among genotypes for all the traits except length of reproductive phase and number of tillers per plant. Significant variations for all the traits were also recorded among the environments. The mean squares due to genotype x environment interaction including environmental linear effects were found to be highly significant for all the traits except panicle length, number of seeds per panicle and harvest index, reflecting differential response of the genotypes at different environments. Genotypes interacted significantly with environments for all the traits except days to 50% heading, days to maturity, harvest index and 100-seed weight. The presence of significant GE interaction indicated that the relative rankings of genotypes were different in different environments.

Further partitioning of the GE interaction into linear and non-linear (pooled deviation) components showed that the linear component of genotype x environment interaction was significant for plant height, length of reproductive phase, number of tillers per plant, panicle length, number of seeds per panicle and grain yield per plant. The nonlinear component (pooled deviation) was significant for all the traits except panicle length. However, when linear component of GE interaction was compared with the pooled deviation, it was found significantly different only for plant height, length of reproductive phase, number of tillers per plant, panicle length, number of seeds per panicle and seed yield per plant, indicating differences in linear response among genotypes in different environments. For the remaining characters i.e., days to

50% heading, days to maturity, harvest index and 100-seed weight, a relatively high proportion of GE interaction was non-linear indicating that prediction of the performance of different genotypes for different environments will not be feasible. In this situation the deviation from regression ( $S^2d_i$ ) is a more important criterion for assessing the stability of genotypes.

For plant height, the linear component of GE interaction was significant for 12 genotypes and nonlinear component for 24 genotypes. Among 25 genotypes, only HD 2733 showed stable performance across the environments. Four genotypes, namely K 9545, HP 1761, HP 1744 and HP 1731 showed regression coefficient close to unity ( $b_i = 1$ ) and the deviation from regression approaching zero ( $S^2d_i = 0$ ) for days to 50% heading. This indicated their average sensitivity to environmental fluctuation for time taken for heading i.e., these genotypes did not respond to environmental conditions and their performance over environments was predictable. Only one genotype, C 306 showed regression coefficient close to unity and the deviation from regression approaching 0 for length of reproductive phase. All the genotypes had significant deviation from regression suggesting that performance of all the genotypes was not predictable and their performance appeared to be unstable with regard to tillers per plant.

Genotypes UP 2472, NW 1014, PBW 466, HUW 520, HD 2733, PBW 450, UP 2003, HUW 516, HP 1838, K 9545, HP 1761, PBW 443, K 9533, C 306, HP 1744, K 8962, HUW 234, HP 2743 and PBW 473 showed unit regression and non-significant deviation from regression for length of panicle. Genotype NW 1012 had unit regression and non-significant deviation from regression indicating phenotypic

stability for days to maturity. All the genotypes showed significant value of deviation from regression for number of seeds per panicle indicating that the performance of seeds per panicle was unpredictable for all the genotypes. One genotype, HP 1731, had unit regression and non-significant deviation from regression suggesting that this genotype was stable for harvest index and its performance was predictable across the environments. All the genotypes showed highly significant deviation from regression suggesting their performance with respect to 100-seed weight was not predictable across the environments.

The range of grain yield per plant varied from 11.59 g in HUW 520 to 30.64 g in HUW 234. A simultaneous evaluation of the stability parameters ( $b_i$  and  $S^2d_i$ ) and mean for grain yield showed that five genotypes, PBW 466, HD 2733, PBW 450, HUW 516 and K 9170 had stable performance as evident from their unit regression and a non-significant deviation from the regression. Out of these genotypes, HD 2733, PBW 450 and K 9170 were the average yielder. PBW 466 and HUW 516 were stable but undesirable due to low yield. NW 1014, K 8027, and PBW 473 were responsive to better growing conditions ( $b_i > 1$ ) of Bundelkhand region while HUW 520, HP 1744 and HP 1731 had regression value less than 1 with non-significant deviation from regression, suggesting that these genotypes were well adapted to poor growing conditions of Bundelkhand region. K 9545 was not only high yielder but also a genotype which responded to good environmental conditions ( $b_i > 1$ ) with predictable performance ( $S^2d_i = 0$ ).

Some of the above stability parameters have been compared statistically elucidating useful empirical interrelationships among them. Based on correlations

between stability parameters, a very strong positive correlation was observed among  $b_i$ ,  $B_i$  and  $\alpha_i$  for all the traits in the present study. The  $b_i$  is often considered to be associated with mean. In this study also,  $b_i$ ,  $B_i$  and  $\alpha_i$  had high correlation with mean of plant height, number of tillers per plant, panicle length, seeds per panicle, 100-seed weight and grain yield per plant. Very strong correlation was observed between all possible pairs among  $S^2d_i$ ,  $\lambda_i$ ,  $\sigma^2_i$  and  $W^2_i$  for plant height, days to 50 per cent heading, length of reproductive phase, number of tillers per plant, panicle length, days to maturity, seeds per panicle, harvest index, 100-seed weight and grain yield per plant. In this study the data do not fit the linear model and consequently, the correlation among  $S^2d_i$ ,  $\lambda_i$ ,  $\sigma^2_i$  and  $W^2_i$  was very high.

Cultivars with high yield and low GE interaction are obviously preferred in any crop species because they are able to express their high yield potential in a range of environmental conditions. However in Bundelkhand environments, the negative impact of a poor crop or crop failure is more important than the positive impact of a rare event such as a good crop. The findings that the morphological and physiological characters associated with high yield under stress conditions are different from those associated with high yield under optimum conditions makes it unwarranted to breed for genotypes with high yield potential for Bundelkhand environments because most of the times the yield potential can not be expressed and a much higher priority should be given to improving yield stability. Furthermore, this suggests that analytical approaches to breeding for yield stability under stress conditions can be made more effective by employing constitutive characters in a selection programmes.

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# TABLES

Table 1. Effects of sowing date and fertilizer application on performance of wheat varieties

Environment	Plant height (cm)	Days to 50% heading	Length of reproductive phase (days)	No. of tillers per plant	Panicle length (cm)	Days to maturity	No. of seeds per panicle	Harvest index (%)	100-seed weight (g)	Grain yield per plant (g)
Normal sown + RDF	115.21 ±1.666	91.31 ±1.928	33.87 ±0.965	17.16 ±0.474	11.84 ±0.603	125.17 ±1.564	59.18 ±0.523	43.18 ±0.974	4.13 ±0.180	31.61 ±2.059
Normal sown + 50% RDF	106.77 ±1.335	67.64 ±1.784	47.82 ±0.909	9.19 ±0.379	10.67 ±1.113	115.46 ±1.314	57.28 ±0.456	40.32 ±1.097	4.22 ±0.132	20.97 ±1.466
Normal sown + No fertilizer	72.93 ±0.943	76.07 ±0.937	50.49 ±0.924	8.40 ±0.398	9.66 ±0.745	126.26 ±1.272	50.01 ±0.708	38.35 ±1.132	3.44 ±0.144	19.84 ±1.698
Late sown + RDF	75.79 ±0.828	86.38 ±1.828	29.82 ±0.996	9.72 ±0.316	10.01 ±0.642	116.20 ±1.341	44.36 ±0.538	39.54 ±1.089	3.97 ±0.107	14.58 ±1.27
Late sown + 50% RDF	71.61 ±0.865	82.84 ±1.478	30.81 ±0.933	8.55 ±0.325	9.42 ±0.670	113.65 ±1.202	42.99 ±0.393	43.54 ±1.452	3.68 ±0.107	12.84 ±1.152
Late sown + No fertilizer	69.44 ±0.873	63.17 ±1.254	36.21 ±0.885	2.98 ±0.328	8.58 ±0.808	99.37 ±0.913	34.99 ±0.464	37.29 ±1.301	3.56 ±0.130	3.24 ±0.095

**Table 2. Analysis of variance for different traits under normal sown condition with recommended dose of fertilizer (environment # 1)**

Source of variation	d.f.	Plant height	Days to 50% heading	Length of reproductive phase	Number of tillers per plant	Panicle length	Days to maturity	Number of seeds per panicle	Harvest index	100-seed weight	Grain yield per plant
Genotypes	24	1060.81**	71.30**	16.12**	33.44**	5.25**	31.83**	365.34**	37.40**	0.87**	141.15**
Error	50	1.162	5.58	1.39	0.34	0.55	3.67	0.41	1.42	0.05	6.36

\* Significant at P = 0.05; \*\*Significant at P = 0.01

**Table 3. Analysis of variance for different traits under normal sown condition with 50% of the recommended dose of fertilizer (environment # 2)**

Source of variation	d.f.	Plant height	Days to 50% heading	Length of reproductive phase	Number of tillers per plant	Panicle length	Days to maturity	Number of seeds per panicle	Harvest index	100-seed weight	Grain yield per plant
Genotypes	24	723.92**	262.96**	75.75**	3.74**	3.69*	63.87**	472.54**	187.38**	1.19**	63.18**
Error	50	2.67	4.77	1.24	0.22	1.86	2.59	0.31	1.81	0.03	3.23

\*Significant at P = 0.05; \*\*Significant at P = 0.01

**Table 4. Analysis of variance for different traits under normal sown condition with no fertilizer (environment # 3)**

Source of variation	d.f.	Plant height	Days to 50% heading	Length of reproductive phase	Number of tillers per plant	Panicle length	Days to maturity	Number of seeds per panicle	Harvest index	100-seed weight	Grain yield per plant
Genotypes	24	341.59**	14.02**	77.35**	2.31**	1.94*	86.45**	254.18**	183.85**	0.78**	61.96**
Error	50	1.33	1.32	1.28	0.24	0.83	2.43	0.75	1.92	0.03	4.33

\* Significant at P = 0.05; \*\*Significant at P = 0.01

**Table 5. Analysis of variance for different traits under late sown condition with recommended dose of fertilizer (environment # 4)**

Source of variation	d.f.	Plant height	Days to 50% heading	Length of reproductive phase	Number of tillers per plant	Panicle length	Days to maturity	Number of seeds per panicle	Harvest index	100-seed weight	Grain yield per plant
Genotypes	24	211.74**	51.19**	71.83**	2.95**	2.17**	24.11**	156.62**	87.98**	0.64**	41.57**
Error	50	1.03	5.01	1.49	0.15	0.62	2.70	0.43	1.78	0.02	2.43

\* Significant at P = 0.05; \*\*Significant at P = 0.01

**Table 6. Analysis of variance for different traits under late sown condition with 50% of the recommended dose of fertilizer (environment # 5)**

Source of variation	d.f.	Plant height	Days to 50% heading	Length of reproductive phase	Number of tillers per plant	Panicle length	Days to maturity	Number of seeds per panicle	Harvest index	100-seed weight	Grain yield per plant
Genotypes	24	266.94**	64.15**	81.79**	2.63**	1.51*	31.27**	148.53**	124.10**	0.68**	29.69**
Error	50	1.12	3.27	1.31	0.16	0.67	2.17	0.23	3.16	0.02	1.99

\* Significant at P = 0.05; \*\*Significant at P = 0.01

**Table 7. Analysis of variance for different traits under late sown condition with no fertilizer (environment # 6)**

Source of variation	d.f.	Plant height	Days to 50% heading	Length of reproductive phase	Number of tillers per plant	Panicle length	Days to maturity	Number of seeds per panicle	Harvest index	100-seed weight	Grain yield per plant
Genotypes	24	277.68**	2.11	9.06**	0.85**	1.52	14.99**	99.24**	48.27**	0.55**	2.51**
Error	50	1.14	2.36	1.18	0.16	0.98	1.25	0.32	2.54	0.03	0.01

\* Significant at P = 0.05; \*\*Significant at P = 0.01

**Table 8. Analysis of variance for stability (Eberhart and Russell model)**

Source of variation	d.f.	Plant height	Days to 50% heading	Length of reproductive phase	Number of tillers per plant	Panicle length	Days to maturity	Number of seeds per panicle	Harvest index	100-seed weight	Grain yield per plant
Replication within environment	12	1.62	4.62	0.33	1.34	0.52	4.18	2.11	2.54	0.07	2.56
Genotypes	24	804.10**	55.46**	48.32**	4.21**	2.71**	12.66*	271.65**	102.34**	1.00**	49.21*
Environment + (Genotype x Environment)	125	439.61**	139.46**	88.73**	22.81**	1.77	108.08**	128.09	48.80	0.21*	102.22**
Environments	5	10189.45**	3008.81**	1918.77**	516.92**	31.47**	2358.69**	2111.72**	160.94**	2.58**	2247.51**
Genotype x Environment	120	33.36**	20.16	12.48**	2.22**	0.53*	14.30	45.43*	44.13	0.11	12.83*
Environment (linear)	1	50947.26**	15044.05**	9593.86**	2584.59**	157.33**	11793.45**	10558.59**	804.70**	12.89**	11237.56*
Genotype x Environment (linear)	24	116.27**	15.75	36.00**	6.31**	1.04**	5.38	93.16**	50.70	0.12	27.32**
Pooled deviation	100	12.13**	20.41**	6.34**	1.15**	0.39	15.87**	32.16**	40.79**	0.11**	8.84**
Pooled error	288	0.60	1.10	0.44	0.02	0.30	0.68	0.05	0.63	0.01	0.95
Total	149	498.32	126.13	82.22	19.81	1.92	92.71	151.21	57.43	0.34	93.68

\* Significant at P = 0.05; \*\*Significant at P = 0.01

**Table 9. Analysis of variance for stability (Perkins and Jinks model)**

Source of variation	d.f.	Plant height	Days to 50% heading	Length of reproductive phase	Number of tillers per plant	Panicle length	Days to maturity	Number of seeds per panicle	Harvest index	100-seed weight	Grain yield per plant
Replication within environment	12	1.62	4.62	0.33	1.34	0.52	4.18	2.11	2.54	0.07	2.56
Genotypes	24	804.10**	55.46**	48.32	4.21	2.71**	12.66*	271.65**	102.34**	1.00**	49.21*
Environment + (Genotype x Environment)	125	439.61**	139.46**	88.73**	22.81**	1.77	108.08**	128.09	48.80	0.21*	102.22**
Environments	5	10189.45**	3008.81**	1918.77**	516.92**	31.47**	2358.69**	2111.72**	160.94**	2.58**	2247.51**
Genotype x Environment	120	33.36**	20.16	12.48**	2.22**	0.53*	14.30	45.43*	44.13	0.11	12.83*
Heterogeneity between regression	24	116.27**	15.75	36.00**	6.31**	1.04**	5.38	93.16**	50.70	0.12	27.32**
Remainder	100	12.63	21.26	6.60	1.20	0.40	16.53	33.50	42.48	0.11	9.20
Pooled error	288	0.60	1.10	0.44	0.02	0.30	0.68	0.05	0.63	0.01	0.95
Total	149	498.32	126.13	82.22	19.81	1.92	92.71	151.21	57.43	0.34	93.68

\* Significant at P = 0.05; \*\*Significant at P = 0.01

**Table 10. Analysis of variance for stability (Freeman and Perkins model)**

Source of variation	d.f.	Plant height	Days to 50% heading	Length of reproductive phase	Number of tillers per plant	Panicle length	Days to maturity	Number of seeds per panicle	Harvest index	100-seed weight	Grain yield per plant
Genotypes	24	1653.53**	112.96**	96.88**	8.25**	6.59**	27.00**	540.26**	203.41**	2.08**	99.51**
Environments	5	20299.89**	6246.26**	3909.45**	1030.62**	69.49**	1931.90**	4208.23**	294.85**	6.32**	4400.18**
Combined regression	1	101444.85**	30990.08**	19540.81**	5152.70**	319.48**	24495.40**	21038.82**	1449.90**	26.44**	21965.25**
Residual (1)	4	13.65**	60.30**	1.61*	0.099	6.99**	41.03**	0.58	6.09**	0.04*	8.91**
Genotype x Environment	120	69.21**	42.55**	26.40**	4.36**	1.39**	28.47**	90.59**	87.42**	0.22**	26.74**
Heterogeneity of regression	24	233.27*_*	34.68	77.38**	12.59**	2.60**	13.42	185.72**	109.78	0.25	52.48**
Residual (2)	96	28.20**	44.51**	13.65**	2.30**	1.08**	32.24**	66.81**	81.83**	0.21**	20.31**
Error between replications	150	1.20	2.05	0.68	0.16	0.73	1.34	0.43	1.19	0.01	1.78

\* Significant at P = 0.05; \*\*Significant at P = 0.01

**Table 11. Analysis of variance for stability (AMMI)**

Source of variation	d.f.	Plant height	Days to 50% heading	Length of reproductive phase	Number of tillers per plant	Panicle length	Days to maturity	Number of seeds per panicle	Harvest index	100-seed weight	Grain yield per plant
Trials	149	498.32**	126.13**	82.22**	19.81**	1.92**	92.71**	151.21**	57.43**	0.34**	93.68**
Genotypes	24	804.10**	55.46**	48.32**	4.21**	2.71**	12.66**	271.65**	102.34**	1.00**	49.21**
Environments	5	10189.47**	3008.81**	1918.77**	516.92**	31.46**	2358.68**	2111.71**	160.94**	2.58**	2247.51**
GE interaction	120	33.36**	20.16**	12.48**	2.22**	0.53**	14.30**	45.43**	44.43**	0.11**	12.83**
PCA I	28	101.44**	60.85**	32.72**	7.57**	1.06**	39.74**	90.77**	113.15**	0.24**	29.17**
PCA II	26	23.24**	18.01**	15.80**	1.28**	0.65**	14.90**	62.56**	60.92**	0.12**	21.79**
PCA III	24	16.28**	7.69**	5.44**	0.63**	0.48*	4.72**	40.11**	11.63**	0.08**	5.92**
Residual	42	4.01**	1.48	0.97**	0.14**	0.13	2.45**	7.65**	6.29**	0.04**	0.33
Error	300	0.64	1.23	0.44	0.07	0.31	0.82	0.13	0.70	0.01	1.02
Total	449	165.79	42.68	27.58	6.62	0.84	31.31	50.27	19.53	0.12	31.77

\* Significant at P = 0.05; \*\*Significant at P = 0.01

**Table 12. Estimates of different stability parameters for plant height**

	Genotype	Mean (cm)	Finley and Wilkinson's $b_i$	Eberhart and Russell's $S^2d_i$	Perkins and Jinks' $B_i$	Tai's $\alpha_i$	Tai's $\lambda_i$	Hanson's $D_i$	Shukla's $\sigma^2_i$	Wricke's $W_i$
1	UP 2472	90.71	1.235**	28.876**	0.235	0.235	23.291	28.049	40.022	186.527
2	NW 1014	93.19	0.895	63.303**	-0.105	-0.105	53.510	17.009	39.453	183.911
3	PBW 466	80.08	0.845*	3.767*	-0.155	-0.155	3.206	9.604	12.166	58.390
4	HUW 520	73.45	0.956	35.429**	-0.044	-0.044	29.703	16.979	19.964	94.261
5	K 8027	99.60	1.400**	3.328*	0.400	0.400	2.622	34.238	72.041	333.815
6	HD 2733	78.43	0.935	2.143	-0.065	-0.065	1.801	13.333	2.549	14.153
7	NW 1012	80.71	1.006	46.047**	0.006	0.006	38.344	19.592	24.984	117.351
8	PBW 450	75.34	0.863	9.937**	-0.137	-0.137	8.436	11.087	13.323	63.712
9	UP 2003	78.77	1.009	10.693**	0.009	0.009	8.900	17.293	5.429	27.400
10	HD 2285	77.11	0.860	16.161**	-0.140	-0.140	13.725	11.667	17.138	81.262
11	NW 1076	79.54	0.757**	10.779**	-0.243	-0.243	9.280	7.327	31.533	147.478
12	HUW 516	82.79	1.148	2.425*	0.148	0.148	1.980	22.901	10.541	50.914
13	HP 1838	84.31	0.907	4.906**	-0.093	-0.093	4.140	12.397	6.014	30.090
14	K 9545	112.18	1.465**	8.366**	0.465	0.465	6.530	37.354	99.888	161.912
15	HP 1761	74.40	0.986	29.289**	-0.014	-0.014	24.452	17.715	15.771	74.972
16	K 9170	98.25	1.157*	4.019**	0.157	0.157	3.278	23.364	12.554	60.174
17	PBW 443	75.12	0.900	13.259**	-0.100	-0.100	11.199	12.958	11.207	53.976
18	K 9533	77.19	0.782**	11.769**	-0.218	-0.218	10.100	8.285	27.117	127.164
19	C 306	111.70	1.617**	37.488**	0.617	0.617	28.614	45.003	188.869	871.222
20	HP 1744	78.10	0.902	4.950**	-0.098	-0.098	4.180	12.186	6.458	32.134
21	K 8962	104.96	1.236**	27.400**	0.236	0.236	22.100	28.004	39.004	183.251
22	HUW 234	85.81	0.966	19.073**	-0.034	-0.034	15.968	16.115	10.553	50.969
23	HP 1731	76.34	0.799**	16.126**	-0.201	-0.201	13.807	9.491	26.314	123.469
24	HP 2743	85.32	0.644**	61.148**	-0.356	-0.356	53.430	12.480	89.522	414.226
25	PBW 473	78.89	0.732**	5.498**	-0.268	-0.268	4.749	5.451	34.411	160.716
	Std error	1.557	0.077							

\*Significant at  $p = 0.05$ , \*\* Significant at  $p = 0.01$

**Table 13. Estimates of different stability parameters for days to 50% heading**

Genotype	Mean (days)	Finley and Wilkinson's $b_i$	Eberhart and Russell's $S^2d_i$	Perkins and Jinks' $B_i$	Tai's $\alpha_i$	Tai's $\lambda_i$	Hanson's $D_i$	Shukla's $\sigma^2_i$	Wricke's $W^2_i$
1 UP 2472	84.45	0.762	112.679**	-0.238	-0.239	98.606	23.638	128.010	592.929
2 NW 1014	72.93	1.056	34.581**	0.056	0.056	28.478	14.953	36.801	173.365
3 PBW 466	82.65	1.054	23.105**	0.054	0.054	19.036	12.882	24.400	1116.319
4 HUW 520	78.86	1.318	19.556**	0.318	0.319	15.206	16.834	33.445	157.928
5 K 8027	83.44	1.093	8.518**	0.093	0.093	6.960	10.400	9.418	47.406
6 HD 2733	79.18	0.821	7.920**	-0.179	-0.179	6.848	6.436	11.822	58.465
7 NW 1012	79.87	1.105	16.073**	0.105	0.106	13.097	12.280	17.892	86.386
8 PBW 450	76.66	1.051	7.054**	0.051	0.051	5.815	9.235	7.054	36.530
9 UP 2003	78.46	0.905	5.554*	-0.095	-0.095	4.720	6.322	6.270	32.924
10 HD 2285	76.90	0.898	5.204*	-0.102	-0.102	4.429	6.085	6.076	32.032
11 NW 1076	76.92	1.077	7.652**	0.077	0.077	6.273	9.891	8.140	41.525
12 HUW 516	80.18	0.844	37.960**	-0.156	-0.156	32.669	13.869	43.203	202.815
13 HP 1838	77.24	0.970	6.103**	0.030	-0.030	5.118	7.514	5.807	30.792
14 K 9545	78.68	0.886	3.909	-0.114	-0.115	3.336	5.349	5.041	27.272
15 HP 1761	80.54	1.096	2.594	0.096	0.096	2.118	8.942	3.104	18.360
16 K 9170	77.91	0.990	6.446**	-0.010	-0.010	5.383	7.961	6.074	32.020
17 PBW 443	76.35	1.126	14.273**	0.126	0.126	11.580	12.269	16.567	80.288
18 K 9533	78.71	1.464**	23.731**	0.464	0.464	17.847	20.350	52.809	247.003
19 C 306	75.87	0.806	10.140**	-0.194	-0.194	8.795	7.173	14.972	72.952
20 HP 1744	74.04	0.937	2.793	-0.063	-0.063	2.358	5.686	2.643	16.240
21 K 8962	75.59	1.050	7.529**	0.050	0.050	6.208	9.352	7.560	38.858
22 HUW 234	72.30	0.805	23.581**	-0.195	-0.195	20.456	10.866	29.493	139.748
23 HP 1731	76.85	0.976	1.656	-0.024	-0.024	1.387	5.985	0.974	8.562
24 HP 2743	73.87	0.855	5.926*	-0.145	-0.145	5.089	5.887	8.242	41.994
25 PBW 473	79.11	1.054	16.979**	0.054	0.054	13.988	11.646	17.798	85.953
Standard error	2.020	0.184							

\*Significant at  $p = 0.05$ , \*\* Significant at  $p = 0.01$

**Table 14. Estimates of different stability parameters for length of reproductive phase**

	Genotype	Mean (days)	Finley and Wilkinson's $b_i$	Eberhart and Russell's $S^2d_i$	Perkins and Jinks' $B_i$	Tai's $\alpha_i$	Tai's $\lambda_i$	Hanson's $D_i$	Shukla's $\sigma^2_i$	Wricke's $W^2_i$
1	UP 2472	32.60	0.151**	9.763**	-0.849	-0.850	8.394	4.137	63.643	294.027
2	NW 1014	40.20	1.240	11.962**	0.240	0.240	9.874	21.823	9.077	43.021
3	PBW 466	34.96	0.728*	20.176**	-0.272	-0.272	16.984	12.778	13.590	63.784
4	HUW 520	37.25	1.354**	5.575**	0.354	0.354	4.585	23.778	12.293	57.816
5	K 8027	35.67	1.410**	41.977**	0.410	0.410	34.446	26.116	29.726	138.007
6	HD 2733	36.91	0.921	6.306**	-0.079	-0.079	5.270	15.450	2.652	13.465
7	NW 1012	36.30	1.162	26.963**	0.162	0.162	22.333	20.971	12.186	57.323
8	PBW 450	40.43	0.982	8.592**	-0.018	-0.018	7.164	16.747	3.025	15.182
9	UP 2003	36.33	0.855	3.338**	-0.145	-0.145	2.796	14.019	2.739	13.869
10	HD 2285	39.30	0.932	4.011**	-0.068	-0.068	3.351	15.544	1.634	8.785
11	NW 1076	37.98	1.150	4.005**	0.150	0.150	3.319	19.763	3.134	15.685
12	HUW 516	33.67	0.746*	13.883**	-0.254	-0.254	11.679	12.663	10.403	49.124
13	HP 1838	38.40	1.121	3.199**	0.121	0.121	2.653	19.161	2.167	11.238
14	K 9545	37.53	0.776	9.885**	-0.224	-0.224	8.306	12.939	7.680	36.595
15	HP 1761	35.88	0.926	3.430**	-0.074	-0.074	2.867	15.383	1.492	8.129
16	K 9170	38.82	0.683*	19.808**	-0.317	-0.317	16.702	11.983	15.647	73.243
17	PBW 443	40.57	1.077	3.652**	0.077	0.077	3.035	18.332	1.615	8.699
18	K 9533	36.66	1.668**	0.469	0.668	0.668	0.381	29.740	37.128	172.057
19	C 306	39.80	0.972	1.337	-0.028	-0.028	1.116	16.174	0.297	2.635
20	HP 1744	40.57	1.072	17.977**	0.072	0.072	14.941	18.899	7.004	33.488
21	K 8962	37.71	1.274*	4.356**	0.274	0.274	3.593	22.177	7.638	36.404
22	HUW 234	45.84	0.758	77.650**	-0.242	-0.242	65.293	16.662	34.210	158.635
23	HP 1731	38.06	1.279*	13.695**	0.279	0.279	11.294	22.634	11.416	53.781
24	HP 2743	43.06	0.668**	42.990**	-0.332	-0.332	36.269	13.339	25.329	117.782
25	PBW 473	38.48	1.096	6.607**	0.096	0.096	5.486	18.838	3.017	15.144
	Standard error	1.126	0.129							

\*Significant at  $p = 0.05$ , \*\* Significant at  $p = 0.01$

**Table 15. Estimates of different stability parameters for number of productive tillers per plant**

Genotype	Mean	Finley and Wilkinson's $b_i$	Eberhart and Russell's $S^2d_i$	Perkins and Jinks' $B_i$	Tai's $\alpha_i$	Tai's $\lambda_i$	Hanson's $D_i$	Shukla's $\sigma^2_i$	Wricke's $W^2_i$
1 UP 2472	10.34	1.109	13.852**	0.109	0.109	6.617	5.451	1.060	5.108
2 NW 1014	9.56	1.016	11.632**	0.016	0.016	9.101	4.509	0.663	3.282
3 PBW 466	9.48	1.154	9.888**	0.154	0.154	3.275	5.784	1.085	5.220
4 HUW 520	8.76	0.949	3.782**	-0.051	-0.051	3.782	3.604	0.239	1.329
5 K 8027	10.72	1.691**	130.891**	0.691	0.693	-185.82	12.555	18.647	86.004
6 HD 2733	10.70	1.307**	8.274**	0.307	0.308	-1.390	7.258	2.573	12.066
7 NW 1012	9.39	0.829	35.474**	-0.171	-0.172	19.374	3.862	2.768	12.965
8 PBW 450	10.06	1.121	0.703**	0.121	0.122	0.308	5.226	0.323	1.717
9 UP 2003	8.99	1.025	2.568**	0.025	0.025	1.933	4.310	0.120	0.782
10 HD 2285	8.95	0.781*	24.202**	-0.219	-0.220	37.459	3.134	2.502	11.739
11 NW 1076	8.46	0.859	2.624**	-0.141	-0.141	3.394	2.680	0.557	2.792
12 HUW 516	9.79	1.317**	17.094**	0.317	0.318	-3.425	7.523	3.249	15.177
13 HP 1838	8.84	0.789*	44.386**	-0.211	-0.212	67.580	3.969	3.656	17.045
14 K 9545	9.88	0.995	6.965**	-0.005	-0.005	5.920	4.163	0.374	1.953
15 HP 1761	7.86	0.826	6.503**	-0.174	-0.174	9.101	2.588	1.023	4.938
16 K 9170	10.74	1.352**	13.187**	0.352	0.352	-4.127	7.789	3.530	16.469
17 PBW 443	9.89	1.140	2.102**	0.140	0.140	0.795	5.447	0.516	2.602
18 K 9533	9.22	0.704**	19.734**	-0.296	-0.297	35.506	2.540	3.123	14.597
19 C 306	9.07	0.998	4.366**	-0.002	-0.002	3.664	4.107	0.216	1.223
20 HP 1744	7.49	0.609**	7.091**	-0.391	-0.392	14.945	1.409	3.815	17.777
21 K 8962	9.08	0.700**	19.792**	-0.300	-0.300	35.825	2.530	3.171	14.818
22 HUW 234	9.61	0.996	5.118**	-0.004	-0.004	4.339	4.108	0.262	1.435
23 HP 1731	8.29	0.700**	15.097**	-0.300	-0.301	27.346	2.254	2.891	13.529
24 HP 2743	8.95	0.986	3.110**	-0.014	-0.014	2.732	3.945	0.144	0.890
25 PBW 473	9.25	1.048	2.268**	0.048	0.049	1.532	4.537	0.141	0.878
Standard error	0.480	0.106							

\*Significant at  $p = 0.05$ , \*\* Significant at  $p = 0.01$

**Table 16. Estimates of different stability parameters for panicle length**

	Genotype	Mean (cm)	Finley and Wilkinson's $b_i$	Eberhart and Russell's $S^2d_i$	Perkins and Jinks' $B_i$	Tai's $\alpha_i$	Tai's $\lambda_i$	Hanson's $D_i$	Shukla's $\sigma^2_i$	Wricke's $W^2_i$
1	UP 2472	11.32	1.020	0.805	0.020	0.020	0.669	2.412	0.198	0.988
2	NW 1014	9.51	1.018	0.892	0.018	0.019	0.742	2.430	0.221	1.094
3	PBW 466	9.83	0.668	0.921	-0.332	-0.338	0.790	1.691	0.379	1.821
4	HUW 520	9.25	0.961	0.652	-0.039	-0.039	0.545	2.238	0.159	0.808
5	K 8027	10.44	2.297**	2.478**	1.297	1.319	1.830	5.677	2.945**	13.625
6	HD 2733	9.34	0.859	0.775	-0.141	-0.143	0.654	2.043	0.217	1.074
7	NW 1012	9.51	1.021	2.813**	0.021	0.021	2.339	2.879	0.733**	3.447
8	PBW 450	9.89	1.056	0.622	0.056	0.057	0.516	2.450	0.153	0.782
9	UP 2003	10.56	0.896	0.662	-0.104	-0.106	0.557	2.090	0.174	0.879
10	HD 2285	9.07	1.174	1.412*	0.174	0.177	1.159	2.901	0.401	1.921
11	NW 1076	9.91	0.879	2.427**	-0.121	-0.123	2.044	2.525	0.649**	3.064
12	HUW 516	10.33	0.815	0.236	-0.185	-0.188	0.200	1.769	0.093	0.504
13	HP 1838	9.47	1.200	0.353	0.200	0.203	0.289	2.730	0.132	0.684
14	K 9545	11.09	1.173	0.209	0.173	0.176	0.171	2.631	0.080	0.444
15	HP 1761	9.85	1.234	0.974	0.234	0.238	0.795	2.945	0.317	1.537
16	K 9170	11.56	1.815**	1.692*	0.815	0.828	1.310	4.432	1.342**	6.249
17	PBW 443	9.56	0.720	0.195	-0.280	-0.285	0.166	1.526	0.142	0.732
18	K 9533	9.79	0.885	1.099	-0.115	-0.117	0.925	2.192	0.294	1.429
19	C 306	10.30	0.654	1.189	-0.346	-0.352	1.020	1.759	0.463*	2.208
20	HP 1744	10.23	0.905	0.508	-0.095	-0.097	0.427	2.066	0.131	0.679
21	K 8962	11.11	1.316	0.426	0.316	0.321	0.345	3.028	0.233	1.150
22	HUW 234	9.45	0.668	0.248	-0.332	-0.338	0.213	1.426	0.200	0.999
23	HP 1731	9.89	0.144**	9.204**	-0.856	-0.871	8.246	3.357	3.437**	15.887
24	HP 2743	9.47	0.726	0.303	-0.274	-0.279	0.259	1.582	0.167	0.846
25	PBW 473	10.08	0.896	0.516	-0.104	-0.106	0.434	2.048	0.135	0.700
	Standard error	0.278	0.248							

\*Significant at  $p = 0.05$ , \*\* Significant at  $p = 0.01$

**Table 17. Estimates of different stability parameters for days to maturity**

Genotype	Mean (days)	Finley and Wilkinson's $b_i$	Eberhart and Russell's $S^2d_i$	Perkins and Jinks' $B_i$	Tai's $\alpha_i$	Tai's $\lambda_i$	Hanson's $D_i$	Shukla's $\sigma^2_i$	Wricke's $W^2_i$
1 UP 2472	117.04	0.841	110.989**	-0.159	-0.160	97.003	19.112	81.260	376.972
2 NW 1014	113.14	0.991	19.916**	-0.009	-0.009	16.644	8.935	13.557	65.536
3 PBW 466	117.61	0.905	30.319**	-0.095	-0.085	26.000	10.170	21.909	103.956
4 HUW 520	116.11	1.094	9.876**	0.094	0.095	7.992	8.306	7.286	36.689
5 K 8027	119.10	1.262	31.927**	0.262	0.262	24.473	14.097	29.175	137.377
6 HD 2733	116.09	0.913	11.415**	-0.087	-0.088	9.766	6.474	8.254	41.142
7 NW 1012	116.17	0.869	1.146	-0.131	-0.131	0.993	2.260	1.878	11.813
8 PBW 450	117.09	0.970	11.727**	-0.030	-0.030	9.863	7.050	7.787	38.995
9 UP 2003	114.79	1.023	6.015**	0.023	0.023	4.978	6.314	3.663	20.026
10 HD 2285	116.20	1.044	13.541**	0.044	0.044	11.132	8.310	9.192	45.458
11 NW 1076	114.90	1.000	15.135**	0.000	-0.000	12.613	8.104	10.130	49.774
12 HUW 516	113.85	0.939	56.932**	-0.061	-0.061	48.324	13.942	40.387	188.954
13 HP 1838	115.64	0.989	6.091**	-0.011	-0.011	5.093	5.841	3.677	20.090
14 K 9545	116.22	0.816	3.601*	-0.184	-0.184	3.169	3.442	5.347	27.770
15 HP 1761	116.43	0.990	8.755**	-0.010	-0.010	7.318	6.558	5.580	28.842
16 K 9170	116.74	0.967	20.630**	-0.033	-0.033	17.367	8.861	14.173	68.367
17 PBW 443	116.91	1.060	16.908**	0.060	0.060	13.833	9.141	11.764	57.288
18 K 9533	115.37	1.230	13.807**	0.230	0.231	10.695	11.234	14.612	70.391
19 C 306	115.67	1.060	20.486**	0.060	0.060	16.760	9.763	14.321	69.052
20 HP 1744	114.61	1.029	6.788**	0.029	0.030	5.606	6.0616	4.253	22.737
21 K 8962	113.30	1.053	3.169*	0.053	0.053	2.598	6.070	1.864	11.747
22 HUW 234	118.14	1.037	20.642**	0.037	0.037	17.005	9.536	14.210	68.542
23 HP 1731	114.90	1.105	8.335**	0.105	0.105	6.722	8.173	6.405	32.635
24 HP 2743	116.92	0.931	18.697**	-0.069	-0.069	15.910	8.227	13.166	63.739
25 PBW 473	117.59	0.882	15.727**	-0.118	-0.118	13.579	7.332	11.981	58.286
Standard error	1.781	0.183							

\*Significant at  $p = 0.05$ , \*\* Significant at  $p = 0.01$

Table 18. Estimates of different stability parameters for number of seeds per panicle

	Genotype	Mean	Finley and Wilkison's $b_i$	Eberhart and Russell's $S^2d_i$	Perkins and Jinks' $B_i$	Tai's $\alpha_i$	Tai's $\lambda_i$	Hanson's $D_i$	Shukla's $\sigma^2_i$	Wricke's $W^2_i$
1	UP 2472	40.99	0.966	250.282**	-0.034	-0.034	222.085	21.043	28.466	137.376
2	NW 1014	50.20	1.429	415.408**	0.429	0.429	59.616	30.920	64.894	304.945
3	PBW 466	39.91	0.115**	144.993**	-0.885	-0.886	327.083	8.905	87.698	409.844
4	HUW 520	42.59	0.805	33.710**	-0.195	-0.195	38.644	14.816	6.090	34.445
5	K 8027	42.33	0.895	148.228**	-0.105	-0.106	148.646	18.372	17.248	85.771
6	HD 2733	44.22	0.438*	92.690**	-0.562	-0.562	160.945	9.735	38.581	183.906
7	NW 1012	43.77	0.678	156.135**	-0.322	-0.322	210.946	14.803	26.685	129.185
8	PBW 450	47.76	1.162	427.883**	0.162	0.162	245.271	26.391	51.883	245.093
9	UP 2003	53.92	1.231	528.509**	0.231	0.232	243.749	28.551	66.363	311.701
10	HD 2285	46.57	1.441	200.536**	0.441	0.441	24.921	29.187	40.300	191.813
11	NW 1076	58.00	0.837	605.861**	-0.163	-0.163	663.639	23.481	73.081	342.605
12	HUW 516	42.07	0.211**	450.632**	-0.789	-0.790	947.382	15.822	109.368	509.527
13	HP 1838	55.14	1.922**	58.352**	0.922	0.923	-37.881	37.555	83.585	390.925
14	K 9545	56.47	1.615*	98.115**	0.615	0.616	-15.305	31.683	45.024	213.543
15	HP 1761	58.68	0.575	623.002**	-0.425	-0.426	945.233	20.733	89.289	417.162
16	K 9170	39.75	0.431*	61.366**	-0.569	-0.569	107.255	8.702	35.594	170.165
17	PBW 443	49.68	1.487	342.509**	0.487	0.488	17.157	31.338	61.112	287.550
18	K 9533	42.02	0.950	160.424**	-0.050	-0.050	146.559	19.546	17.906	88.802
19	C 306	45.81	0.602	287.951**	-0.398	-0.398	424.183	16.049	47.376	224.361
20	HP 1744	43.48	1.112	21.760**	0.112	0.112	14.225	20.765	2.336	17.176
21	K 8962	53.69	1.029	220.023**	0.029	0.029	173.134	21.744	24.841	120.702
22	HUW 234	51.23	1.166	285.041**	0.166	0.166	161.418	24.944	35.028	167.559
23	HP 1731	59.72	1.599*	183.982**	0.599	0.599	-23.782	32.091	53.382	251.988
24	HP 2743	38.96	0.728	30.681**	-0.272	-0.272	38.968	13.248	9.025	47.946
25	PBW 473	56.42	1.575*	52.125**	0.575	0.575	-4.739	30.465	35.134	168.048
	Standard error	2.536	0.276							

\*Significant at  $p = 0.05$ , \*\* Significant at  $p = 0.01$

**Table 19. Estimates of different stability parameters for harvest index**

Genotype	Mean (%)	Finley and Wilkinson's $b_i$	Eberhart and Russell's $S^2d_i$	Perkins and Jinks' $B_i$	Tai's $\alpha_i$	Tai's $\lambda_i$	Hanson's $D_i$	Shukla's $\sigma^2_i$	Wricke's $W^2_i$
1 UP 2472	30.75	0.683	15.852**	-0.317	-0.322	14.059	11.783	8.604	47.738
2 NW 1014	40.39	-0.717	71.318**	-1.717	-1.745	80.141	14.260	62.391	295.155
3 PBW 466	38.38	-0.152	58.100**	-1.152	-1.171	59.736	13.706	42.978	205.855
4 HUW 520	40.78	1.658	28.072**	0.658	0.668	20.270	17.640	18.390	92.751
5 K 8027	42.39	0.596	7.189**	-0.404	-0.410	6.480	10.255	3.755	25.432
6 HD 2733	46.08	-1.029	267.646**	-2.029	-2.061	314.854	27.413	190.386	883.933
7 NW 1012	38.98	0.963	23.494**	-0.037	-0.038	19.725	13.916	12.575	66.005
8 PBW 450	39.40	0.361	28.061**	-0.639	-0.649	26.416	11.872	18.210	91.925
9 UP 2003	47.02	4.013**	192.374**	3.013	3.061	62.308	36.854	179.156	832.276
10 HD 2285	44.88	1.447	21.722**	0.447	0.454	16.460	16.070	12.882	67.414
11 NW 1076	39.53	1.733	5.591**	0.733	0.745	3.966	16.163	5.402	33.001
12 HUW 516	37.64	0.726	11.344**	-0.274	-0.278	9.978	11.445	5.674	34.260
13 HP 1838	34.63	0.917	2.481*	-0.083	-0.084	2.102	11.352	-0.212	7.183
14 K 9545	43.29	1.406	139.127**	0.406	0.413	106.386	24.113	84.298	395.930
15 HP 1761	38.68	0.949	12.007**	-0.051	-0.052	10.110	12.632	5.574	33.796
16 K 9170	35.73	1.106	12.928**	0.106	0.108	10.541	13.528	6.196	36.659
17 PBW 443	39.32	3.066	15.395**	2.066	2.099	7.452	24.141	37.478	180.558
18 K 9533	36.18	1.544	126.479**	0.544	0.553	93.761	23.837	77.496	364.641
19 C 306	42.45	1.517	28.470**	0.517	0.525	21.239	16.984	17.470	88.521
20 HP 1744	47.99	3.378*	203.108**	2.378	2.416	87.589	34.573	161.761	752.258
21 K 8962	37.66	-0.804	14.552**	-1.804	-1.833	16.566	6.518	29.880	145.607
22 HUW 234	41.17	-0.598	23.837**	-1.598	-1.624	26.307	8.537	30.655	149.169
23 HP 1731	39.59	0.370	1.097	-0.630	-0.640	1.031	8.126	1.675	15.861
24 HP 2743	47.01	0.058	19.122**	-0.942	-0.957	18.982	9.575	16.111	82.269
25 PBW 473	39.14	1.810	123.357**	0.810	0.823	85.909	24.610	78.106	367.444
Standard error	2.856	1.126							

\*Significant at  $p = 0.05$ , \*\* Significant at  $p = 0.01$

**Table 20. Estimates of different stability parameters for 100-seed weight**

	Genotype	Mean (g)	Finley and Wilkinson's $b_1$	Eberhart and Russell's $S^2d_i$	Perkins and Jinks' $B_i$	Tai's $\alpha_i$	Tai's $\lambda_i$	Hanson's $D_i$	Shukla's $\sigma^2_i$	Wricke's $W_i^2$
1	UP 2472	3.875	1.114	7.200**	0.114	0.118	5.610	0.810	0.054	0.272
2	NW 1014	3.634	0.753	10.968**	-0.247	-0.254	10.422	0.733	0.090	0.435
3	PBW 466	3.853	1.793	22.754**	0.793	0.816	10.426	1.441	0.248	1.162
4	HUW 520	3.188	0.613	15.913**	-0.387	-0.398	16.174	0.810	0.139	0.663
5	K 8027	4.513	0.948	20.292**	-0.052	-0.053	17.408	1.002	0.158	0.749
6	HD 2733	4.001	1.152	2.033**	0.152	0.156	1.548	0.707	0.014	0.087
7	NW 1012	3.686	0.900	3.583**	-0.100	-0.103	3.155	0.595	0.025	0.137
8	PBW 450	3.461	0.585	8.171**	-0.415	-0.427	8.414	0.601	0.080	0.390
9	UP 2003	3.657	0.873	9.298**	-0.127	-0.131	8.307	0.741	0.072	0.351
10	HD 2285	3.541	1.100	22.025**	0.100	0.103	17.311	1.091	0.173	0.816
11	NW 1076	3.631	0.486	0.147**	-0.514	-0.529	0.158	0.189	0.026	0.141
12	HUW 516	3.702	1.152	8.486**	0.152	0.156	6.462	0.859	0.066	0.324
13	HP 1838	3.421	0.658	20.032**	-0.342	-0.352	19.937	0.909	0.169	0.798
14	K 9545	4.172	1.226	3.974**	0.226	0.233	2.886	0.803	0.033	0.173
15	HP 1761	3.219	0.724	24.488**	-0.276	-0.284	23.605	1.011	0.200	0.941
16	K 9170	4.576	0.639	5.610**	-0.361	-0.371	5.633	0.536	0.055	0.274
17	PBW 443	3.744	1.226	4.824**	0.226	0.233	3.503	0.822	0.040	0.204
18	K 9533	4.161	1.340	2.136**	0.340	0.350	1.437	0.836	0.025	0.138
19	C 306	4.591	1.985*	29.494**	0.985	1.014	10.827	1.628	0.340	1.587
20	HP 1744	3.904	0.740	3.977**	-0.260	-0.268	3.804	0.523	0.035	0.181
21	K 8962	4.088	0.885	4.930**	-0.115	-0.118	4.376	0.628	0.036	0.188
22	HUW 234	4.009	0.559	10.806**	-0.441	-0.454	11.262	0.670	0.104	0.498
23	HP 1731	3.384	0.243	29.575**	-0.757	-0.779	35.239	1.044	0.296	1.385
24	HP 2743	4.443	2.359**	13.488**	1.359	1.399	2.567	1.675	0.310	1.449
25	PBW 473	3.462	0.946	7.637**	-0.054	-0.055	6.558	0.732	0.057	0.283
	Standard error	0.147	0.457							

\*Significant at  $p = 0.05$ , \*\* Significant at  $p = 0.01$

**Table 21. Estimates of different stability parameters for grain yield per plant**

Genotype	Mean (g)	Finley and Wilkinson's $b_i$	Eberhart and Russell's $S^2d_i$	Perkins and Jinks' $B_i$	Tai's $\alpha_i$	Tai's $\lambda_i$	Hanson's $D_i$	Shukla's $\sigma^2_i$	Wricke's $W^2_i$
1 UP 2472	14.74	1.032	10.917**	0.032	0.032	9.058	11.015	9.392	44.970
2 NW 1014	20.99	1.293*	30.835**	0.293	0.293	24.685	18.168	35.335	164.307
3 PBW 466	15.29	0.857	2.950	-0.143	-0.143	2.506	6.132	4.218	21.172
4 HUW 520	11.59	0.619**	3.256	-0.381	-0.382	2.852	3.643	16.700	78.587
5 K 8027	20.64	1.467**	8.316**	0.467	0.467	6.496	18.893	28.254	131.735
6 HD 2733	18.11	1.051	2.279	0.051	0.051	1.886	9.663	1.893	10.475
7 NW 1012	14.75	0.801	4.063*	-0.199	-0.199	3.477	5.615	7.076	34.319
8 PBW 450	18.52	1.110	1.523	0.110	0.110	1.250	10.715	2.155	11.682
9 UP 2003	18.26	1.234	8.542**	0.234	0.234	6.895	14.311	12.525	59.383
10 HD 2285	15.18	0.938	8.518**	-0.062	-0.062	7.157	8.971	7.542	36.461
11 NW 1076	17.45	0.824	6.232*	-0.176	-0.176	5.316	6.659	8.165	39.324
12 HUW 516	14.24	0.968	3.432	-0.032	-0.032	2.873	8.287	2.760	14.464
13 HP 1838	16.39	1.058	11.667**	0.058	0.058	9.647	11.587	10.284	49.074
14 K 9545	23.04	1.408**	1.569	0.408	0.408	1.236	16.916	17.251	81.124
15 HP 1761	16.51	0.875	12.179**	-0.125	-0.125	10.320	8.894	11.941	56.696
16 K 9170	18.79	1.188	2.538	0.188	0.188	2.062	12.489	5.319	26.237
17 PBW 443	16.26	0.907	13.940**	-0.093	-0.093	11.761	9.708	12.809	60.687
18 K 9533	15.49	0.653**	11.871**	-0.347	-0.348	10.354	6.994	21.922	102.607
19 C 306	19.18	1.214	4.933*	0.214	0.214	3.993	13.385	8.447	40.624
20 HP 1744	12.44	0.625**	2.644	-0.375	-0.376	2.315	3.286	15.708	74.025
21 K 8962	21.61	1.074	26.363**	0.074	0.074	21.751	14.163	23.514	109.931
22 HUW 234	30.64	0.734	22.019**	-0.266	-0.266	19.004	9.784	26.045	121.576
23 HP 1731	14.58	0.651*	3.200	-0.349	-0.349	2.792	3.676	14.356	67.806
24 HP 2743	16.99	1.107	4.172*	0.107	0.107	3.427	11.148	4.439	22.187
25 PBW 473	17.80	1.312*	8.829**	0.312	0.313	7.049	15.883	16.980	79.876
Standard error	1.329	0.140							

\*Significant at  $p = 0.05$ , \*\* Significant at  $p = 0.01$

Table 22. Correlation coefficients among different stability parameters for plant height

Eberhart									
Finlay and Wilkinson's		Perkins and Jinks' $B_i$		Tai's $\alpha_i$	Tai's $\lambda_i$	Hanson's $D_i$	Shukla's $\sigma^2_i$	Wricke's $W^2_i$	
Mean	$b_i$	$S^2d_i$							
Mean	1.000								
$b_i$	0.815**	1.000							
$S^2d_i$	0.145	-0.045	1.000						
$B_i$	0.815**	1.000**	-0.045	1.000					
$\alpha_i$	0.815**	1.000**	-0.045	1.000**	1.000				
$\lambda_i$	0.116	-0.086	0.999**	-0.086	-0.086	1.000			
$D_i$	0.858**	0.973**	0.151	0.974**	0.973**	0.113	1.000		
$\sigma^2_i$	0.721**	0.596**	0.378	0.596**	0.596**	0.351	0.704**	1.000	
$W^2_i$	0.602**	0.496**	0.443*	0.496**	0.496**	0.416*	0.610**	0.948**	1.000

\* Significant at  $P = 0.05$ ; \*\* Significant at  $P = 0.01$

Table 23. Correlation coefficients among different stability parameters for days to 50% heading

Eberhart									
		Finlay and Wilkinson's	and	Perkins	Tai's		Hanson's	Shukla's	Wricke's
Mean		$b_i$	$S^2d_i$	Jinks' $B_i$	$\alpha_i$	$\lambda_i$	$D_i$	$\sigma^2_i$	$W^2_i$
Mean	1.000								
$b_i$	0.121	1.000							
$S^2d_i$	0.410*	-0.189	1.000						
$B_i$	0.117	0.997**	-0.196	1.000					
$\alpha_i$	0.120	1.000**	-0.189	0.997**	1.000				
$\lambda_i$	0.410*	-0.220	0.999**	-0.227	-0.221	1.000			
$D_i$	0.410*	0.404*	0.804**	0.394*	0.404*	0.783**	1.000		
$\sigma^2_i$	0.403*	-0.053	0.976**	-0.061	-0.053	0.970**	0.873**	1.000	
$W^2_i$	0.480*	0.032	0.550**	0.025	0.031	0.542**	0.535**	0.539**	1.000

\* Significant at  $P = 0.05$ ; \*\* Significant at  $P = 0.01$

**Table 24. Correlation coefficients among different stability parameters for length of reproductive phase**

	Finlay and Wilkinson's Mean $b_i$	Eberhart and Russell's $S^2d_i$	Perkins and Jinks' $B_i$	Tai's $\alpha_i$	Tai's $\lambda_i$	Hanson's $D_i$	Shukla's $\sigma_i^2$	Wricke's $W_i^2$
Mean	1.000							
$b_i$	0.078	1.000						
$S^2d_i$	0.478*	-0.200	1.000					
$B_i$	0.078	1.000**	-0.200	1.000				
$\alpha_i$	0.078	1.000**	-0.200	1.000**	1.000			
$\lambda_i$	0.481*	-0.209	1.000**	-0.209	1.000			
$D_i$	0.142	0.983**	-0.039	0.982**	-0.047	1.000		
$\sigma_i^2$	-0.167	-0.294	0.443*	-0.295	0.445*	-0.151	1.000	
$W_i^2$	-0.167	-0.294	0.443*	-0.295	0.445*	-0.151	1.000**	1.000

\* Significant at  $P = 0.05$ ; \*\* Significant at  $P = 0.01$

Table 25. Correlation coefficients among different stability parameters for number of productive tillers per plant

Eberhart								
Finlay and Wilkinson's		Perkins and Jinks' $B_i$		Tai's $\alpha_i$	Tai's $\lambda_i$	Hanson's $D_i$	Shukla's $\sigma_i^2$	Wricke's $W_i^2$
Mean	$b_i$	$S^2 d_i$						
Mean	1.000							
$b_i$	0.813**	1.000						
$S^2 d_i$	0.306	0.421*	1.000					
$B_i$	0.813**	1.000**	0.421*	1.000				
$\alpha_i$	0.813**	1.000**	0.420*	1.000**	1.000			
$\lambda_i$	-0.451*	-0.758**	-0.710**	-0.758**	-0.758**	1.000		
$D_i$	0.806**	0.963**	0.627**	0.963**	-0.795**	1.000		
$\sigma_i^2$	0.295	0.462*	0.954**	0.462*	-0.773**	0.655**	1.000	
$W_i^2$	0.295	0.462*	0.954**	0.462*	-0.773**	0.655**	1.000**	1.000

\* Significant at  $P = 0.05$ ; \*\* Significant at  $P = 0.01$

Table 26. Correlation coefficients among different stability parameters for panicle length

Eberhart									
Finlay and Wilkinson's		Perkins and Jinks' B <sub>i</sub>		Tai's α <sub>i</sub>	Tai's λ <sub>i</sub>	Hanson's D <sub>i</sub>	Shukla's σ <sup>2</sup> <sub>i</sub>	Wricke's W <sup>2</sup> <sub>i</sub>	
Mean	b <sub>i</sub>	S <sup>2</sup> d <sub>i</sub>							
Mean	1.000								
b <sub>i</sub>	0.395*	1.000							
S <sup>2</sup> d <sub>i</sub>	-0.038	-0.236	1.000						
B <sub>i</sub>	0.395*	1.000**	-0.236	1.000					
α <sub>i</sub>	0.394*	1.000**	-0.236	1.000**	1.000				
λ <sub>i</sub>	-0.048	-0.280	0.999**	-0.280	-0.280	1.000			
D <sub>i</sub>	0.370	0.785**	0.413*	0.785**	0.785**	0.373	1.000		
σ <sup>2</sup> <sub>i</sub>	0.132	0.196	0.852**	0.196	0.195	0.830**	0.725**	1.000	
W <sup>2</sup> <sub>i</sub>	0.132	0.196	0.852**	0.196	0.195	0.830**	0.725**	1.000**	1.000

\* Significant at  $P = 0.05$ ; \*\* Significant at  $P = 0.01$

Table 27. Correlation coefficients among different stability parameters for days to maturity

Eberhart								
Finlay and Wilkinson's		Perkins and Russell's	Jinks' B <sub>i</sub>	Tai's α <sub>i</sub>	Tai's λ <sub>i</sub>	Hanson's D <sub>i</sub>	Shukla's σ <sup>2</sup> <sub>i</sub>	Wricke's W <sup>2</sup> <sub>i</sub>
Mean	b <sub>i</sub>	S <sup>2</sup> d <sub>i</sub>						
Mean	1.000							
b <sub>i</sub>	-0.018	1.000						
S <sup>2</sup> d <sub>i</sub>	0.185	-0.225	1.000					
B <sub>i</sub>	-0.018	1.000**	-0.225	1.000				
α <sub>i</sub>	-0.015	1.000**	-0.225	1.000**	1.000			
λ <sub>i</sub>	0.176	-0.252	0.999**	-0.252	-0.252	1.000		
D <sub>i</sub>	0.219	0.216	0.884**	0.216	0.217	0.870**	1.000	
σ <sup>2</sup> <sub>i</sub>	0.221	-0.178	0.994**	-0.178	-0.178	0.992**	0.897**	1.000
W <sup>2</sup> <sub>i</sub>	0.221	-0.178	0.994**	-0.178	-0.178	0.992**	0.897**	1.000**

\* Significant at P = 0.05; \*\* Significant at P = 0.01

Table 28. Correlation coefficients among different stability parameters for number of seeds per panicle

Eberhart									
Finlay and Wilkinson's		Perkins and Jinks' $B_i$		Tai's $\alpha_i$	Tai's $\lambda_i$	Hanson's $D_i$	Shukla's $\sigma^2_i$	Wricke's $W^2_i$	
Mean	$b_i$	$S^2 d_i$							
Mean	1.000								
$b_i$	0.602**	1.000							
$S^2 d_i$	0.409*	-0.102	1.000						
$B_i$	0.602**	1.000**	-0.102	1.000					
$\alpha_i$	0.602**	1.000**	-0.102	1.000**	1.000				
$\lambda_i$	0.065	-0.609**	0.719**	-0.609**	-0.609**	1.000			
$D_i$	0.735**	0.936**	0.207	0.936**	0.936**	-0.317	1.000		
$\sigma^2_i$	0.377	-0.087	0.631**	-0.087	-0.087	0.608**	0.224	1.000	
$W^2_i$	0.377	-0.087	0.631**	-0.087	-0.087	0.608**	0.224	1.000**	1.000

\* Significant at  $P = 0.05$ ; \*\* Significant at  $P = 0.01$

Table 29. Correlation coefficients among different stability parameters for harvest index

Eberhart															
Finlay and Wilkinson's		Perkins and		Jinks' B <sub>i</sub>		Tai's		Hanson's		Shukla's		Wricke's			
b <sub>i</sub>		S <sup>2</sup> d <sub>i</sub>		S <sup>2</sup> d <sub>i</sub>		α <sub>i</sub>		λ <sub>i</sub>		D <sub>i</sub>		σ <sup>2</sup> <sub>i</sub>		W <sup>2</sup> <sub>i</sub>	
Mean															
Mean	1.000														
b <sub>i</sub>	0.232	1.000													
S <sup>2</sup> d <sub>i</sub>	0.535**	0.235	1.000												
B <sub>i</sub>	0.232	1.000**	0.235	1.000											
α <sub>i</sub>	0.232	1.000**	0.235	1.000**	1.000										
λ <sub>i</sub>	0.390*	-0.180	0.869**	-0.180	-0.180	1.000									
D <sub>i</sub>	0.501**	0.703**	0.840**	0.703**	0.703**	0.553**	1.000								
σ <sup>2</sup> <sub>i</sub>	0.576**	0.292	0.975**	0.292	0.292	0.798**	0.858**	1.000							
W <sup>2</sup> <sub>i</sub>	0.576**	0.292	0.975**	0.292	0.292	0.798**	0.858**	0.858**	1.000**	1.000					

\* Significant at  $P = 0.05$ ; \*\* Significant at  $P = 0.01$

Table 30. Correlation coefficients among different stability parameters for 100-seed weight

Eberhart															
Finlay and Wilkinson's		Russell's		Perkins and Jinks' B <sub>i</sub>		Tai's		Tai's		Hanson's		Shukla's		Wricke's	
b <sub>i</sub>		S <sup>2</sup> d <sub>i</sub>				α <sub>i</sub>		λ <sub>i</sub>		D <sub>i</sub>		σ <sup>2</sup> <sub>i</sub>		W <sup>2</sup> <sub>i</sub>	
Mean	1.000														
b <sub>i</sub>	0.545**	1.000													
S <sup>2</sup> d <sub>i</sub>	-0.126	0.127	1.000												
B <sub>i</sub>	0.545**	1.000**	0.127	1.000											
α <sub>i</sub>	0.545**	1.000**	0.127	1.000**	1.000										
λ <sub>i</sub>	-0.424*	-0.372	0.839**	-0.372	-0.372	1.000									
D <sub>i</sub>	0.278	0.760**	0.717**	0.760**	0.760**	0.312	1.000								
σ <sup>2</sup> <sub>i</sub>	0.079	0.398*	0.901**	0.398*	0.398*	0.620**	0.860**	1.000							
W <sup>2</sup> <sub>i</sub>	0.079	0.398*	0.901**	0.398*	0.398*	0.620**	0.860**	0.860**	1.000**	1.000					

\* Significant at  $P = 0.05$ ; \*\* Significant at  $P = 0.01$

Table 31. Correlation coefficients among different stability parameters for grain yield per plant

	Finlay and Wilkinson's Mean $b_i$	Eberhart and Russell's $S^2 d_i$	Perkins and Jinks' $B_i$	Tai's $\alpha_i$	Tai's $\lambda_i$	Hanson's $D_i$	Shukla's $\sigma^2_i$	Wricke's $W^2_i$
Mean	1.000							
$b_i$	0.418*	1.000						
$S^2 d_i$	0.494*	0.097	1.000					
$B_i$	0.418*	1.000**	0.097	1.000				
$\alpha_i$	0.418*	1.000**	0.097	1.000**	1.000			
$\lambda_i$	0.498**	0.064	0.999**	0.064	0.064	1.000		
$D_i$	0.592**	0.940**	0.395*	0.940**	0.367	1.000		
$\sigma^2_i$	0.457*	0.127	0.724**	0.127	0.719**	0.406*	1.000	
$W^2_i$	0.457*	0.127	0.724**	0.127	0.719**	0.406*	1.000**	1.000

\* Significant at  $P = 0.05$ ; \*\* Significant at  $P = 0.01$